DIGITAL SIMULATION OF BEAS SUTLEJ SYSTEM

A Thesis Submitted
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MASTER OF TECHNOLOGY

by

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to the

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INDIAN INSTITUTE OF TECHNOLOGY KANPUR

NOVEMBER 1978

DEDICATED

TO

MY PARENTS

CERTIFICATE

This is to certify that the thesis " Digital Simulation of Beas-Sutlej System " submitted by Shri Vijendra Singh in partial fulfilment of the requirements for the degree of Master of Technology of the Indian Institute of Technology, Kanpur, is a record of bonafide research work carried out by him under my supervision and guidance. The work embodied in this thesis has not been submitted elsewhere for a degree.

Dated November ,1978

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Vijendra Singh

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LIST OF SYMBOLS, ABBREVIATIONS, OR NOMENCLATURE

Symbols

ARCS	Total number of arcs in the network
C_{ij}	Cost of flow from node i to node j for time Δt
H	Net head
i	Index for node
j	Index for node
L_{ij}	Lower bound of the arc from node i to node j
L_B	Lower limit of average state
n	Number of nodes
N	Number of reservoirs used in identifying the state of the system
N_D	Number of demand nodes
N_L	Number of river reaches and canals
N_N	Number of reservoirs and nonstorage junctions
N_S	Number of spill nodes
q_{ij}	Flow from node i to node j for time Δt
R	Total water available for storage or use
S	Shortage
S_i	Capacity of the ith reservoir
$S_{i,t}$	Desired storage for ith reservoir in t^{th} time period
t	Period under consideration
U_{ij}	Upper bound of the arc from node i to node j
U_B	Upper limit of average state
W	Total storage capacity of reservoirs defining the state of the system; Total desired storage in an average year in the reservoirs defining the state of the system.

$X_{i,t}$	End of month storage for the ith reservoir in the t^{th} time frame
X_1	Fraction of W to define L_B lower limit of average state
X_2	Fraction of W to define U_B upper limit of average state
$Y_{i,t+1}$	Unregulated inflows to the ith reservoir in the $(t+1)^{th}$ time frame
Z	Objective function
Δt	Time interval
η	Efficiency

Abbreviations

BBDO	Bhakra Beas Design Organization
BBMB	Bhakra Beas Management Board
BBS	Bhakra Beas System
BDO	Beas Design Organization
BMB	Bhakra Management Board
BSL	Beas Sutlej Link
CS	Cusecs
m.a.f.	Million acre feet
m.cu.m.	Million cubic meters
MBL	Madopur Beas Link
MW	Megawatts
TAF	Thousand acre feet
TWDB	Texas Water Development Board
WJC	Western Jamuna Canal

Nomenclature

Cumec day	One cubic meter per second flowing per one day (86400 cu.m.)
Kharif	Monsoon season, June-October
Non-Kharif	Non monsoon season, November-May
Rabi	Dry season, November-February
Water Year	June 1, to May 31.

SYNOPSIS

"Digital Simulation of Beas Sutlej System" - a thesis submitted in partial fulfilment of the requirements for the Degree of Master of Technology by Vijendra Singh to the Department of Civil Engineering, Indian Institute of Technology, Kanpur, November 1978.

Water resources systems are generally large and complex. They consist of multiple units and serve multiple purposes. The multiple purposes are not wholly complementary. Several general or problem specific simulation models and computer programmes have been developed for analysing water resources systems. SIMYLD II is a computer programme developed by Texas Water Development Board for simulating the hydrologic operation of a system of interconnected reservoirs within a basin or a multibasin water resources system. The study consists in implementing the SIMYLD II programme, validating it with available data and adapting it for the operation of Bhakra Beas system.

The original SIMYLD II programme was implemented in IBM 7044-1401 system at I.I.T. Kanpur and was adapted to meet the requirements of Bhakra Beas system.

Using 13 years of historical data, the Bhakra Beas system was simulated using the modified SIMYLD II model. The criteria for defining wet, average and dry years; the rule curves for operation in wet, average and dry years; and

the relative weightages for meeting different demands and for maintaining the rule curves are derived from simulation analysis. Results indicate that by using these criteria, the benefit from the operation of the system can be greatly increased. Further improvement of the model is also possible.

1. INTRODUCTION

1.1 General

1.1.1 Water resources planning

Water resources systems are generally large and complex. They consists of multiple units and they serve multiple purposes. The multiple purposes are not wholly complementary Water resources systems are designed to serve several socio-economic objectives like national and regional economic development, income distribution, preservation and enhancement of Environmental quality and social well being (Maass et al., 1962, United States Water Resources Council, 1973). They are also affected by economic and hydrologic uncertainties.

The conventional practice in planning, design and operation of water resources projects has been to consider a set of demands and to satisfy them by river basin development. Such a development includes the purposes it is to serve, the physical means for meeting these purposes, the sizes of needed facilities and the levels of output. Based on experience, a few alternatives are proposed, analysed and evaluated through incremental analysis before a final design is adopted.

Planning can be defined as the orderly consideration of a project from the original statement of purpose through the evaluation of alternatives to the final decision on a course of action. It is the basis for decision to proceed with a proposed project and is clearly the most important aspect of

the total engineering for the project. The planning for an entire river basin involves a much more complex planning effort than that for a single project, but the difficulties in arriving at the correct decision may be just as great for the smaller project.

Hufschmidt considers the field level planning of water resources systems to consist of four hierarchical steps, viz. (Cole, 1975).

i) Definition of project objectives and agreement of these with policy makers;

ii) Securing staff and scheduling their tasks;

iii) Data assembly on the physical variables (hydrology, water quality), human requirements (water supply, land use, recreation); and economic quantities (construction and operation costs, explicit benefits); and

iv) Formulation of system design via (a) screening of alternative configurations and (b) detailed analysis of remaining components.

Planning may deal with modification to and operation of an existing system, or the design of an essentially new system involving the operating variables also. The latter is naturally more complicated. The two parts of step iv imply that initially a large number of alternatives are to be considered, and so relatively crude models are used to essentially eliminates trivial and inferior alternatives and isolate better alternatives. This is generally done by programming models.

Once better alternatives are identified, it may be possible to consider more detailed models of the system and arrive at the "best" one. This may involve stochastic programming and simulation models.

Wiener (1972) considers the role of planner and system analyst in the socio-economic development process in an underdeveloped country where water is used as a critical input for economic development and progress. He deems it necessary to consider the implementation phase also in planning particularly in the case of underdeveloped countries. He also indicates the limitations and opportunities in the application of system analysis and operations research techniques in water resources planning.

1.1.2 Simulation analysis

To simulate means to duplicate the essence of a system or activity without attaining reality itself. Simulation has been used traditionally in engineering. The use of conceptual system models, scale models, analogues and laboratory experimentation are but some of the general simulation techniques traditionally used in engineering. Simulation has been used for a number of purposes including the analysis of the system to estimate the parameters and the behaviour of the system that is existing or is yet to be; the effect of the environment on the system design; the demonstration of the performance of a new complex system, and for giving training in the control of complex systems.

Digital simulation is the numerical simulation of the process in a digital computer. A behaviour model of the physical components of a water resources system is formulated in terms of the components parameters, variables and relationships among them to study the processes as they evolve in time through the several components of the system when subjected to a series of hydrologic inputs and human interventions in terms of design, construction and operation of the system. When the mathematical model for a process has been decided upon, the various elements of the process can be represented on the computer so that outputs from one part of a system constitute inputs to one or more elements of the system or to itself. The system is simulated for a set of design and operating parameters, and the effect of changes in these parameters on the system response is investigated.

The simulation of any system involve generally a number of steps which can be represented as follows(Fig.1.1):

i) Formulation of the problem : The problem is to be formulated in analytic terms. This involves the definition of the objective, their priorities, the approach to optimization, the identification of the system and its environment and the structure of the system.

ii) Analysis of data : The historical data for the inputs, the components of the system, and the outputs are collected.

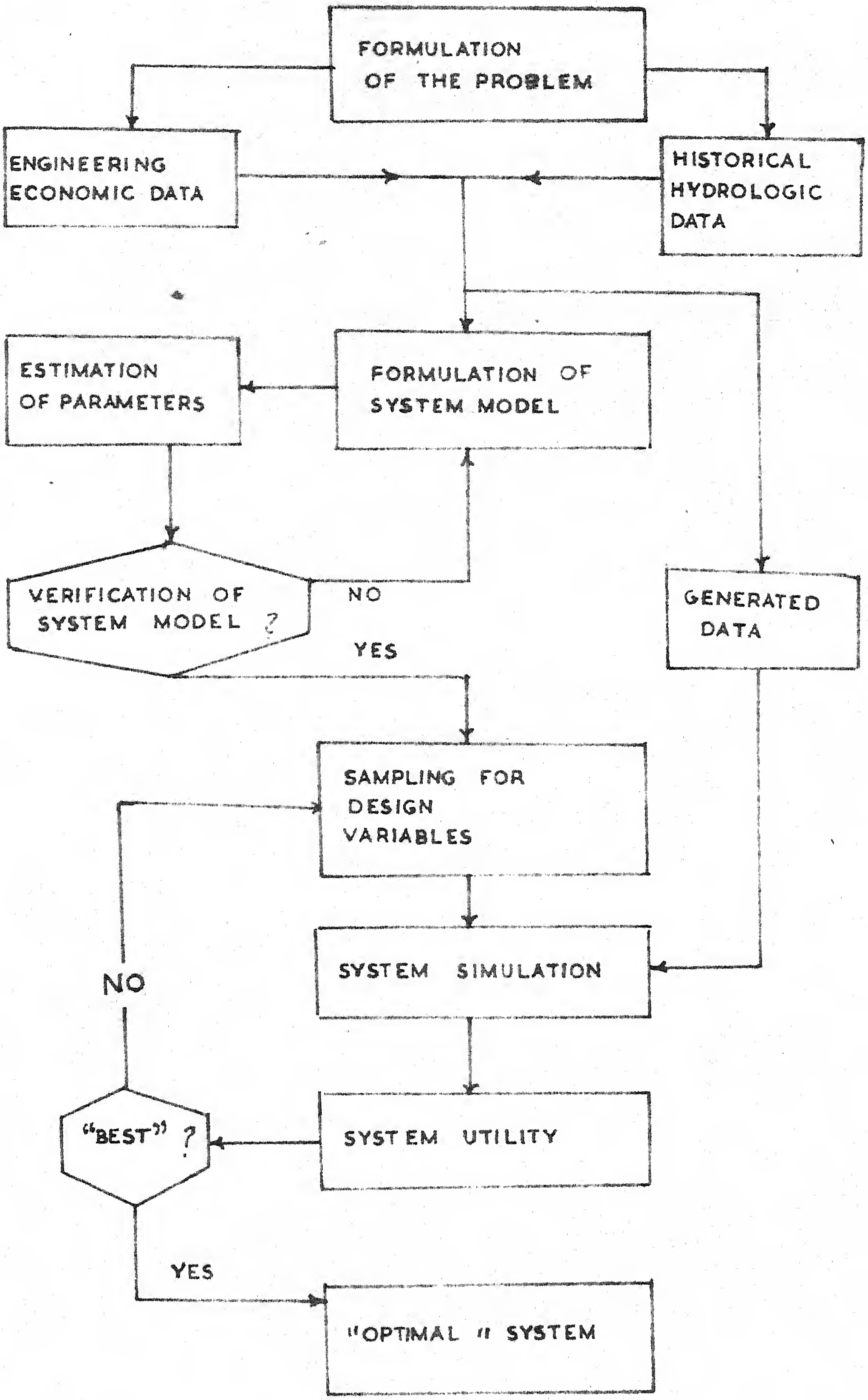


FIG. 1.1 STEPS IN SIMULATION

iii) Formulation of system model : Initially component models are formulated; from the data of the previous step, parameter values are estimated for the component models; and the models are validated. A flow diagram for the system indicating the sequence of the modifications of the inputs by the system is prepared.

iv) Estimation of parameters and validation of system model: The parameters of the system are estimated, the system is analysed or numerically simulated and from the responses of the system for hypothetical or historical inputs as per record and from the results of simulation, the formulated system model is validated.

v) Sampling for design variables : A set of feasible and preferred design and operating parameters are chosen.

vi) Simulation of the process : The system is digitally simulated using historical or generated data as the case may be.

vii) System utility : The measure of system response in achieving the goals for the system parameters assumed in each case is evaluated.

The results of simulation are also analysed to determine whether the system design can be improved with reference to the achievement of the goals. The parameter values are modified, and steps vi and vii are repeated until the "best" of the alternatives considered is identified.

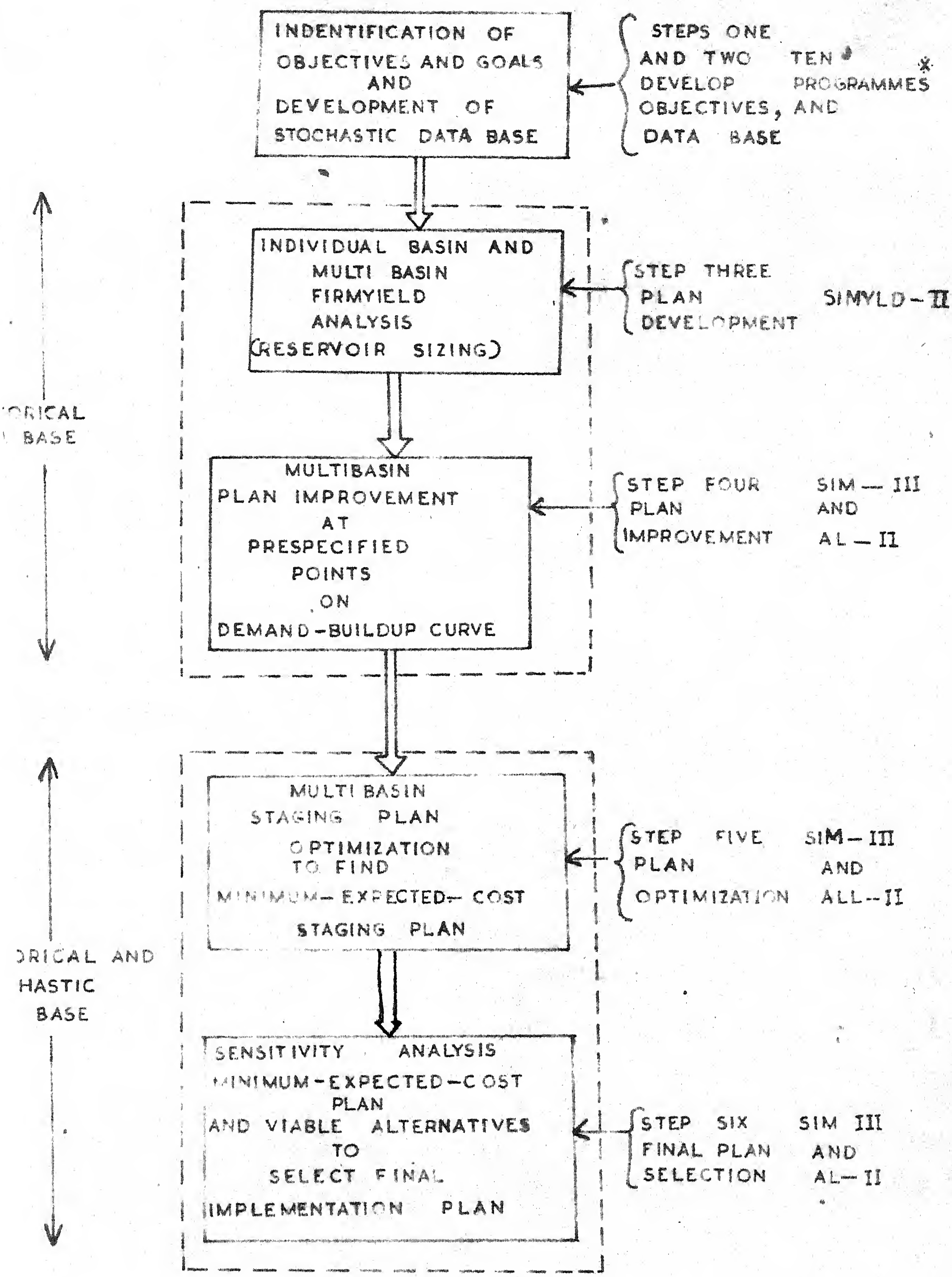
viii) "Reporting of results:The results of the study, the conclusions drawn and the recommended system design are reported in the final step for implementation.

1.1.3 Planning models of TWDB

Several general or problem specific simulation models and computer programmes have been developed for analysing water resources systems. Important references include Maass et. al. (1962), Hufschmidt and Fiering (1966), Lucia et al (1971), U.S. Army Corps of Engineers Hydrologic Engineering Centre (1968), and Texas Water Development Board (1972, 1972a, 1974). The general approach to simulation may be based on heuristic criteria as in the case of Maass et.al.(1962), Hufschmidt and Fiering (1966) or may use an imbedded optimisation technique as in the case of Texas Water Resources Board (1972),

Texas Water Development Board (TWDB) began in 1967 long range programme of applied research in water resources system simulation and optimization. The objective was to develop a set of generalised computer oriented planning tools for use in detailed planning, design and management of water resources systems such as the Texas Water System as proposed in the Texas Water Plan. Project II refers to the second phase of a three phase research project leading towards the development of a computer oriented planning system for use in planning of large, multibasin systems of reservoirs and connecting river reaches and pumped canals. The six planning steps of project II are shown in Fig. 1.2. They include :

USED



step two requires the use of Ten data preparation Programmes.

G. 1. 2 PROCEDURAL PLANNING STEPS FOR PROJECT II

Step 1 : Identification of objectives and goals - This step outlines the problem to be solved, specifies in general the magnitude and location of demands to be met and the priorities associated with meeting each of the specified demands, identifies the sources of the water to be considered, and identifies the criterion to be used in optimising the selection of an implementation plan.

Step 2 : Data base development - In this step both historical and stochastically generated hydrologic data sets are developed concurrent with the economic and physical data.

Step 3 : Plan development - This step analyses each of the individual river basins to determine their firm yield characteristics and the location of possible attractive basin import and export points.

Step 4 : Plan improvement - This step improves those plans such that minimum - cost plans are developed at each of several points on a prespecified demand - build up curve.

Step 5 : Plan optimisation - It optimises the staging plan over the time period when demands for water are increasing. This implies finding the minimum - expected cost plan that meets the demands specified with an optimal level of shortages.

Step 6 : Final plan selection - This is the final step in the planning procedure and involves testing the sensitivity of the cost and physical response of the simulated prototype to variation in all of the important parameters used by the models.

1.1.4 SIMYLD II programme

SIMYLD II is a computer programme designed to simulate the hydrologic operation of a system of interconnected reservoirs within a basin or a multibasin water resources system. The inputs to the model are physical description of the system to simulate operating criteria and monthly inflows, monthly demands and monthly evaporation rates. The output consists of monthly end of month reservoir storages, monthly flows in the system's river reaches and canals, and annual end period of simulation summaries. The main attributes of the model are simplicity in set up and use, generality in application, and speed of computation. Other models are more comprehensive and naturally much more complicated. Since SIMYLD II is used in earlier steps in decision making than the other models (Fig. 1.2) and it is also useful in identifying surplus and deficits, it is proposed to implement SIMYLD II at IBM 7044-1401 system at I.I.T.Kanpur and test it for field data of a river basin.

1.2 Statement of Problem

It is proposed to implement SIMYLD II programme developed by the TWDB, validate the programme using the test data given in the TWDB report publication on the model (TWDB,1972), adapt the simulation programme if necessary to meet the requirement of water resources systems in India,and test and validate the adapted model using some data for an Indian river basin.

1.3 Objective of the Study

The major objective of the study is to implement and adapt the SIMYLD II programme of TWDB to suit requirement of a river basin in India, identify the limitations and capabilities of such a model and hence develop knowhow for more comprehensive development planning models.

1.4 Scope of the Study

The scope of the study is limited by i) available data for real systems; ii) time availability for the study; iii) limited interactions with field engineers and planners; and iv) limitations in the IBM 7044-1401 computer system at I.I.T. Kanpur.

Hence the scope is limited to the following :

i) Because of the limited capacity of the IBM 7044-1401 system, simulation is limited to 13 nodes, 20 links and 13 years.

ii) The data were available for Bhakra-Beas system for a number of years and because of the limitation in time, computer capacity and computer availability, the studies are limited to the following :

a) While Bhakra Beas Management Board (BBMB) adopt a ten daily operation of the system, only monthly operation is considered in this study;

b) Only 13 years of data values are used in this study;

c) Because of limitation of the data availability and non avoidable lumping of demands and supplies in the model,

certain assumptions were made with reference to allocation of demands for different sources and for the lumping of demands at nodes;

d) The demands are defined by BBMB for dry, dependable and average years. The inflows in the system may be dry, average or wet. Certain reasonable assumptions were made to link the demands to the inflows and these are considered in great detail in Chapter 4; and

e) Because of the limitations of the study, model needs further modification as indicated in Chapter 5.

1.5 Significance of the Study

As the remaining available uncommitted supplies of water and land resources diminish and demands for them increase, the objectives of water resources planning broaden the physical facilities required become more complex, and the limitations under which they must be implemented become more stringent. There exists an urgent need to develop techniques which can enhance the capability of the planners to make an intelligent and comprehensive evaluation of alternatives. Because costs of construction, operation, and maintenance of water resources facilities are likely to be large, a means must be found for analysing alternative solutions to water problem. Planners have been turning to sophisticated mathematical techniques applied on digital computers of increasing speed and accuracy. This study will lead to a better understanding of the problems in managing our scarce national water resource and towards a

better tool in the design of optimum water resources systems in India.

1.6 Organization of the Study

The study is reported in the following sequence :

i) Chapter 2 discusses the River basin simulation Model SIMYLD II and indicates the capabilities and limitations of the original programme;

ii) Implementation of programme SIMYLD II is discussed in Chapter 3. Modifications, additions and alterations in the programme on IBM 7044-1401 systems to suit Indian conditions are also described;

iii) Chapter 4 discusses the use of the adaptations of SIMYLD II in the simulation of Beas-Sutlej System. System description and input data required by the model are described briefly. A comparison is made in study of planned operation and improvements in operation. Results obtained and tentative conclusions are also discussed; and

iv) Summary, conclusions and suggestions for future study are presented in Chapter 5.

2. RIVER BASIN SIMULATION MODEL, SIMYLD II

2.1 Introduction

SIMYLD II is a computer programme developed by TWDB designed to simulate the operation of the system of inter-connected reservoirs within a basin or a multibasin water resources system. The description of the model and its various details have been taken from several publications of the TWDB (particularly TWDB, 1972).

2.2 Model Description

2.2.1 Purpose

The purpose of SIMYLD-II is to provide the water resource planner with a tool for analysing water storage and water transfer within a multireservoir or multibasin system. The model has the following uses to the planner :

i) It simulates the movement of water in a system of reservoirs, rivers, and conduits on a monthly basis while trying to meet a set of specified demands in a given order of priority. If a shortage occurs (i.e., not all demands can be met for a particular time period) during the operation, they are spatially located at the lowest priority demand nodes;

ii) It determines the firm yield of a reservoir within a water resources system. Firm yield is defined as the maximum demand at a reservoir that can be met with 'acceptable' shortages;

iii) The model is designed to provide the user with flexibility in selecting operating rules for each reservoir. The operating rules are formulated as the percentage of the reservoir capacity (either total or conservation) that is desired to be held in storage at the end of each month. In addition to it, priority ranking, used to determine the allocation of water between meeting demands and maintaining storage is assigned to each storage reservoir;

iv) The model can analyse either static or dynamic system operation, in that both constant or time-variable demands can be analysed; and

v) The user can analyse the operation of the system under the expected ultimate demands for any selected hydrologic sequence.

The model is designed to simulate both small scale systems, such as two or three reservoirs within one river basin, and large scale systems, such as the proposed Texas Water System.

2.2.2 Concepts

The concept behind SIMYLD-II is that the physical water resource system can be transformed into a capacitated network flow problem. While making this transformation, the physical elements of the real system are represented as a combination of two possible network components -- nodes and links.

As the nomenclature implies, a node is a connection and/or branching point within the network. Therefore, a node is similar to a reservoir or non-storage junction (i.e. canal junctions, major river intersections, etc.) in the physical system. Along with this, a node is a network component which is considered to have the capacity to store a finite and bounded amount of the material moving in the network. In the case of SIMYLD-II, reservoirs are represented by nodes which have a storage capacity as well as the ability to serve as branching points. A nonstorage capacitated junction is treated similar to a capacitated junction (reservoirs) except that its storage capacity is always zero. Demands placed on the system must be located at nodal points.

The transfer of water among the various network nodes is fulfilled by transfer components called links. A link is a river reach, canal, or closed conduit with a specified direction of flow and a fixed maximum and minimum capacity. The physical system and its basic time step operation, in this case a month, is formulated as the network flow problem. The network flow problem is nothing more than a mathematical representation of the physical system. This mathematical representation is accomplished as follows :

i) Reservoirs and nonstorage junctions are represented by nodes;

ii) River reaches and pumped canals are represented by links; and

iii) Additional information needed to describe the system, such as inflows, demands, spill points, and starting conditions are specified by the user.

An initial step in the application of SIMYLD-II is the construction of the node-link diagram describing the physical system. In designing the node-link diagram, the physical system elements are represented by diagram elements in the following manner :

(i) Reservoirs are represented by triangles ;

(ii) Non-storage junctions or branching points are represented by circles ;

(iii) River reaches are represented by ~~dashed~~ Solid lines showing the directions of flow ; and

(iv) Canals or closed conduits are represented by ~~solid~~ dashed lines showing the direction of flow.

In order to make the node-link diagram conform to the requirements of SIMYLD-II, the following rules for designing the diagram should be followed :

i) Water can enter or leave the system only at node points (either storage or non-storage nodes). Inflows (over land flow, tributaries, etc.), link losses (evaporation, seepage, etc.) and demands can be lumped at the closest node. If more detail is required, additional non-storage nodes can be inserted at critical locations ;

ii) The numbering system used to describe the nodes consists of numbering all nodal reservoirs consecutively followed by numbering all non-storage nodes ; and

iii) Number all river reaches consecutively followed by all canals and/or conduits in the same manner as described above. Figure 2.1 shows this node arc configuration formulated as a network flow problem.

Once the node-link diagram is complete, all nodes, links, and other information must be described in terms of directed, capacitated arcs and nodes. Within the typical network there are seven types of nodes. These are :

i) Reservoir nodes ;
ii) Non-storage nodes ;
iii) Initial storage and inflow nodes ;
iv) Demand nodes ;
v) Spill nodes ;
vi) Final storage nodes ; and
vii) Net balance nodes

Connecting these seven types of nodes are seven types of arcs. Flows in these arcs are constrained to be within specified upper and lower limits. The seven types of arcs are :

i) Physical system link arcs (river reaches, pumped canals, etc.) ;
ii) Initial storage and inflow arcs ;

iii) End of month desired storage arcs (operating rules);

iv) Balance of final storage and maximum reservoir capacity arcs ;

v) Demand arcs ;

vi) Spill arcs ; and

vii) Net balance arcs.

Table 2.1. shows the arc types and their upper and lower bound constraints. The total number of arcs in any network is given by :

$$ARCS = N_L + 3(N_N) + N_D + N_S + 4 \qquad \ldots \qquad (2.1)$$

Where

N_L = number of river reaches and canals,

N_N = number of reservoirs and non-storage junctions,

N_D = number of demand nodes,

N_S = number of spill nodes, and

4 = number of balance arcs.

Cost per unit of flow is associated with each arc in the network. These unit cost coefficients are used to find the minimum cost solution to the network flow problem. As input to the model, the user selects priorities for meeting demands and satisfying final end-of month storage requirements in the reservoirs. These priorities are then converted into the above mentioned costs by the programme. Demand arc and desired storage arc costs are expressed as negative costs (analogous to benefits). The more negative

TABLE 2.1 ARC TYPES AND DEFINITIONS OF THEIR UPPER AND LOWER BOUNDS (TWDB, 1972)

	Arc Type	Lower Bound	Upper Bound
1.	Physical system link		
a.	River Reach	Minimum River Capacity+ (User Specified)	Maximum River Capacity
b.	Canal, Pipe line	Minimum Canal Capacity+ (User Specified)	Maximum Canal Capacity
2.	Initial Storage and Inflow	Previous End-of-Month Storage Plus Current Monthly Inflows	Previous End-of-Month Storage Plus Current Monthly Inflows
3.	Final Desired Storage	Reservoir Minimum Pool (User Specified)	Percent of maximum Capacity Desired (monthly operating rules)
4.	Final Storage Balance	Zero	Balance Between Maximum Capacity and Upper Bound of 3.
5.	Demand Arc	Zero	Demand at Node.
6.	Spill Arc	Zero	System Capacity Multiplied by 10
7.	Net Balance		
a.	Total Initial Storage Plus Inflows	Σ Initial Storages	Σ Initial Storages
b.	Total Final Storage Arc	Σ Final Storage Balance Plus Σ Final Desired Storage	Σ Final Storage Balance plus Σ Final Desired Storage
c.	Total Demands	Zero	Σ Demands
d.	Total Spills	Zero	Σ Spills

+ Should be zero unless minimum flow is required. However a minimum flow requirement may cause infeasible solutions.

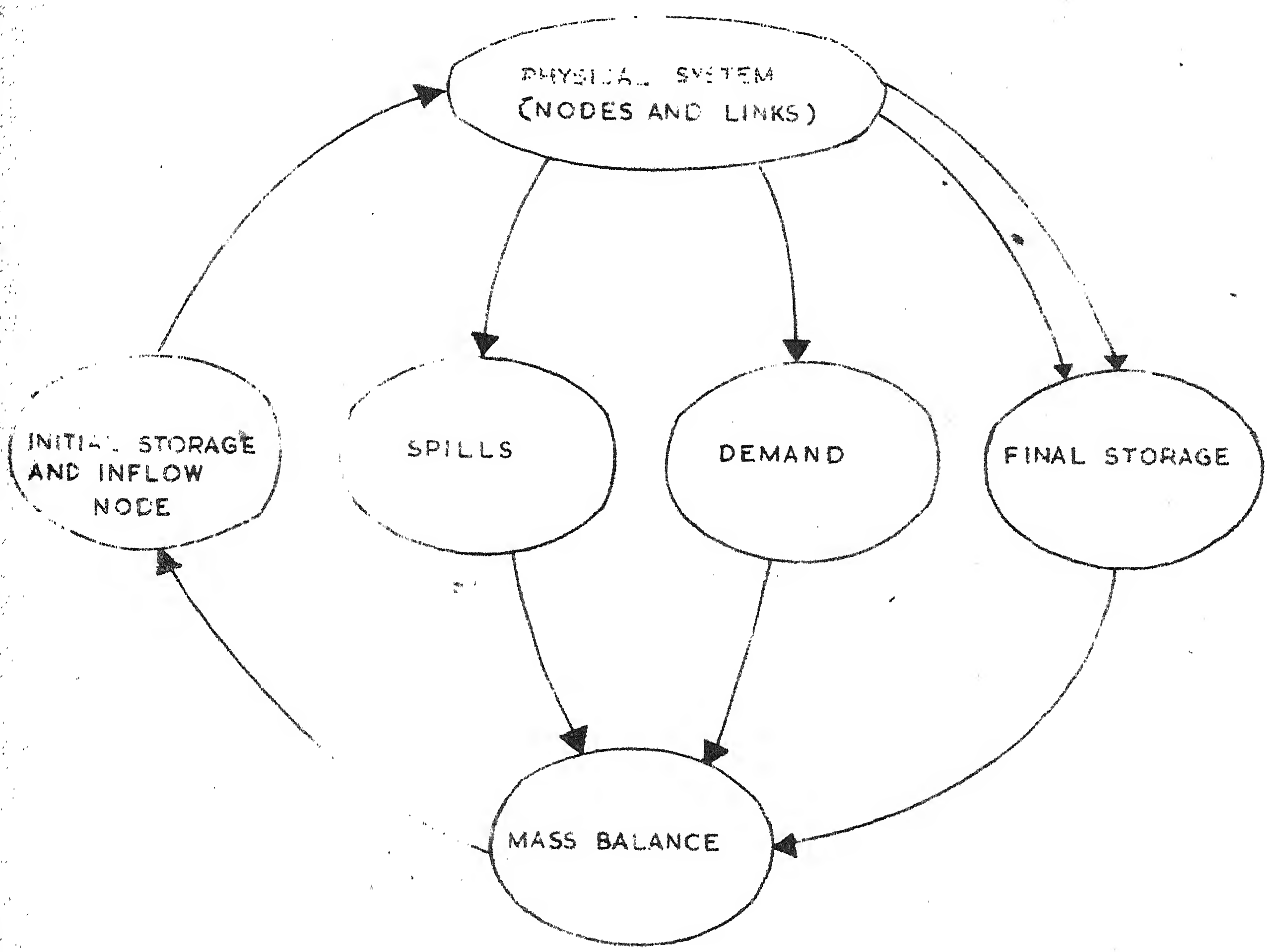


FIG. 2.1 NODE ARC CONFIGURATION AS A NETWORK FLOW PROBLEM

the number, the higher the priority for meeting the upper constraint (demand or storage). Physical system link and spill costs, on the other hand, are positive costs. The effect is to meet demands and desired storage in the order of the priorities while minimising the canal pumping and spills from the system. It may be noted that high rank indicates the lower priority and vice-versa.

2.2.3 Assumptions

i) Evaporation losses for all reservoirs are calculated by the product of the monthly evaporation rate and the aver monthly reservoir surface area ;

ii) Demands for water are known for the month being simulated ;

iii) Unregulated inflows to the system are known for the month being simulated ;

iv) Reservoir storage contents are allowed to fluctuate between the maximum and minimum capacities specified by the user ;

v) Spills occur only at specified nodes and are the mos expensive alternative ; and

vi) The flow in all links ranges between the maximum and minimum capacity specified by the user.

2.2.4 Steps

The procedure adopted in the programme makes use of the following four steps in moving from a known set of state variables at the beginning of a time step to the solution

for the required set of state variables at the end of the time step. The four solution steps are summarized as follows:

i) The present status of the network is evaluated and all system elements are given an appropriate parametric description ;

ii) All specified hydraulic and hydrologic inputs and demands are accounted for, and the mass balance for the entire network system is determined. Bounds are placed on system demands, spills and storage levels.

iii) The flows necessary to meet the levels required by (Eq. 2.3), and at the same time minimise the system's total cost of water transport, are determined through the application of an optimisation procedure.

The mathematical formulation of the directed capacitated network problem is as follows :

MINIMISE :

$$Z = \sum_{ij} q_{ij} C_{ij} \qquad \ldots \qquad (2.2)$$

Subject to :

$$\sum_i q_{ij} - \sum_i q_{ji} = 0, \quad j = 1, \ldots . n \qquad \ldots \qquad (2.3)$$

$$L_{ij} \leq q_{ij} \leq U_{ij}, \text{ all } i, j \qquad \ldots \qquad (2.4)$$

where

q_{ij} = Flow from node i to node j for time Δt;

C_{ij} = Cost of flow from node i to node j for time Δt;

L_{ij} = Lower bound of the arc from node i to node j; and

U_{ij} = Upper bound of the arc from node i to node j

The first set of constraints (Eq.2.3) satisfies continuity of mass at all nodes in the network. Eq. 2.4 describes the upper and lower limits on flow in all arcs in the network. The objective function to be minimised is expressed by Eq. 2.2.

iv) All necessary state variables have now been determined, and the status of the system at the conclusion of the current time step becomes the status at the beginning of the next time step.

This procedure is repeated in a step-wise fashion until a specified simulation interval has been spanned.

In SIMYLD-II the optimal allocation of network flows is accomplished through the application of the " Out-of-Kilter Algorithm" (Ford and Fulkerson, 1962). This procedure finds the minimum total cost of water circulation within the network system subject to flow constraints placed on the system arcs. If we define the amount of water flowing in arc (i,j), from node i to node j, as q_{ij}, and the unit cost of moving water in this link as C_{ij}, then the algorithm minimizes the objective function $Z = \Sigma\ C_{ij}\ q_{ij}$ for all i and j in the system. This is accomplished subject to the flow constraints given in Eqs. 2.3 and 2.4. The 'Out-of-Kilter Algorithm' requires

the objective function and all constraints to be linear and therefore, SIMYLD-II can be considered to be a linear programming formulation.

2.2.5 Programme description

SIMYLD-II consists of a main programme and eleven subroutines, all of which are written in Fortran IV programming language . Fig.2.2 shows the organization of the code the subroutine names and calling programme.

The following is a description of the important features of each of the subroutines.

SIMYLD-II (Main Programme)

The main programme is the control point for calling subroutines. The Fortran logical unit requirements are read in and their values are kept throughout programme execution.

Subroutine ADJUST

This subroutine is used to adjust the annual demands in the firm yield calculations. This adjustment is based on the greatest shortage incurred during the period of operation. When the shortage demand ratio is within the user specified tolerance, or the preset value of 10 percent, it returns to subroutine OPRATE with input = 0 value.

Subroutine CARDS

Subroutine CARDS reads all input from Cards except for the monthly variable data(inflows, demands, and evaporation rates).

Subroutine DATA 1

This subroutine is called only if variable monthly data (inflows, demands,and evaporation rates) are being read from cards. The data cards are read, rearranged, and a temporary scratch file is written for use by the programme.

ENTRY DATA 2

This entry point within subroutine DATA 1, permits the programme to read one year of monthly data during simulation. The temporary scratch file is written from a previous call to DATA 1 or is created in advance.

ENTRY RULE

This entry point is where the monthly operating rule criteria is set. The preselected subsystem of reservoirs is analysed to determine if it falls in the average, dry, or wet state and the appropriate operating rule is passed on to OPRATE.

Subroutine OPRATE

This is the major subroutine in the programme and is where the yearly and monthly loops are set and all calls to operating parts of the model take place. The arc

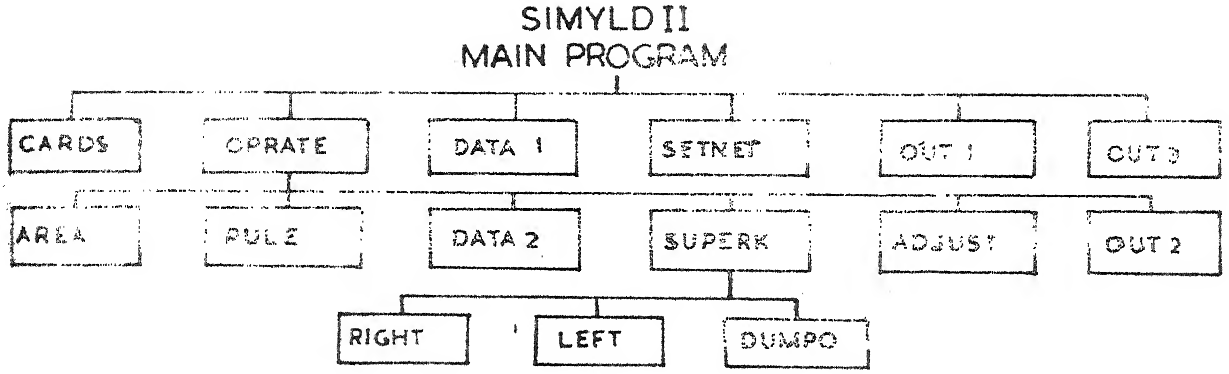


FIG. 2. 2 ORGANIZATION OF SIMYLD II

bounds and unit flow costs are calculated in this routine. This subroutine also controls the calls to ADJUST and DATA 2 for iteration if the model is operating in the firm yield mode. Upon return from the network flow algorithm, initial arrays and yearly total summaries are set up. Based on an input operation, selected years are passed on to OUT 2 for printing.

Subroutine AREA

This subroutine performs a linear interpolation to determine reservoir surface area as a function of volume. The user is permitted to input up to 18 matched points per reservoir to describe the area - capacity relationship of each reservoir in the system.

Subroutine OUT 2

OUT 2 prints detailed monthly system operation for selected years. At the end of each simulation year, OPRATE determines if the year should be printed and issues a call to OUT 2. Detailed monthly information for each node and link is printed including beginning and ending storages, inflows, demand, spills, transfer amounts, etc.

Subroutine OUT 1

This subroutine provides a complete printing of the input variables that control the simulation. These variables have been read previously by subroutine CARDS.

Subroutine OUT 3

Subroutine OUT 3 is an output subroutine called from SIMYLD-II (Main Programme) after the simulation is completed. This subroutine prints summaries of the annual operation of each node for each year in the simulation period. In addition, simulation period totals and maximum and average flows in each link are printed.

Subroutine SETNET

This subroutine is called to set up the basic network system. The configuration is determined by the number of nodes and physical links which are joined to mass balance nodes by artificial links as described previously.

Subroutine SUPERKIL

This subroutine finds the minimum cost flow in the network. As described previously, costs are determined from the ranking priorities supplied by the user. The routine is called by OPRATE for every month of simulation where the bounds and priorities have been assigned.

Subroutine RIGHT Entry LEFT

This subroutine and entry point are intimately related to the operation of the subroutine SUPERKIL.

2.3 Capabilities and Limitations

SIMYLD-II is capable of simulating the operation of a system of interconnected reservoirs and non-storage

junctions with a maximum of 30 nodes (reservoirs and non-storage junctions) interconnected by a maximum of 45 links. The maximum simulation period, using monthly intervals is 30 years.

Unit identifications have been purposely deleted from output files so that the model can use acre-feet, thousands of acre-feet, metric system units, etc. as units of flow and storage as required by the user.

The model allows for three sets of operating policies to guide the model through corresponding hydrologic states. These hydrologic states are determined by the programme each month from the value of storages and inflows in a specified group of reservoirs.

The model accepts card input for the monthly data for a system consisting of upto 20 nodes and for a simulation period of less than 21 years. For larger systems or longer simulation periods, a binary tape must be prepared.

In some cases, the algorithm in SIMYLD-II causes the simulation to be terminated due to infeasibility in solving the network problem. In almost every case, these infeasibilities are caused by in proper specifications by the user. The most common are :

i) Improper system configuration ;

ii) The user has not allowed an adequate number of spill nodes ;

iii) A minimum canal capacity is too binding ;

iv) An unregulated inflow occurs where there is no possible way to reallocate the water in the system, that is, no spill node has been provided, and

v) Basic data problems

Most of the above problems, can be readily avoided by carefully examining the schematic diagram and verifying that the data are correct.

3. IMPLEMENTATION OF SIMYLD-II PROGRAMME

3.1 General

SIMYLD-II is a fairly lengthy programme involving around 1400 FORTRAN Cards. Available core memory in IBM 7044 at I.I.T. Kanpur is less than 32 K. words. This is not adequate for the original SIMYLD-II programme. Two compilers are available for IBM- 7044 viz. (i) WATFOR, (ii) FORTRAN IV. WATFOR Compiler gives an extensive diagnostic report but memory availability is less and diagnostic checking is slow. Due to memory problem, and even for debugging purpose, the whole programme could not be run at a time. Main programme and each subroutine were fed separately on WATFOR compiler for correcting the syntax errors.

3.2 Modification due to Computer System

SIMYLD-II was developed by Carles D. Puentes of the Systems Engineering Division of the Texas Water Development Board on a third generation Computer System. This is to be implemented in the IBM 7044-1401 system at I.I.T. Kanpur using Fortran IV compiler. While correcting the syntax errors of main and subroutine programmes, problems arose :

i) The notation for continuity card is changed from A,B,C etc. to 1,2,3 etc. to suit the computer system ;

ii) Entry statements were used in the original programmes e.g. ENTRY DATA 2 and ENTRY RULE in Subroutine DATA 1 and ENTRY LEFT and ENTRY DUMPO in subroutine RIGHT. Since entry

statements are inadmissible in the IBM 7044- 1401 system, the following modifications were made to the programme :

a) Since ENTRY DATA 2 and ENTRY RULE which occur in subroutine DATA 1, are called only once each and that too in subroutine OPRATE, those were incorporated in subroutine OPRATE itself ;

b) ENTRY LEFT and ENTRY DUMPO have been implemented as separate subroutines ;

iii) Some read cards had to be changed to suit the computer e.g. READ(KIN, 11, END = 22) (TITLE (I), I=1,20) was chaged to

```
ASSIGN 22 TO LOC
CALL FXMSET (LOC, IFLAG,-7,38)
READ (KIN,11) ( TITLE (I), I = 1,20)
```

iv) After removing the syntax errors, the complete programme was fed and it was found to result in large memory overflow. The original programme is capable of simulating the monthly operation of a system of interconnected reservoirs and non-storage junctions with a maximum of 30 nodes and 45 links over a period of 30 years. In order to reduce the memory requirements to the capacity of IBM 7044-1401 system, it was necessary to reduce the dimension of the variables. It was found that a system with 13 nodes and 20 links can be simulated using monthly intervals over a period of 13 years.

3.3 Validation of the Original Programme

The original publication describing SIMYLD-II (TWDB 1972) gave the test data for a hypothetical system and the programme was run using the test data. The results from the simulation run agreed with the results given in the original publication and thus the programme implementation was validated.

3.4 Additions and Alterations

3.4.1 Water year

In the original programme the water year is counted from first January to thirty first December. In this study, the water year is modified to begin on June Ist of one year and ends on the thirty first May of the next year.

3.4.2 Canal system

SIMYLD-II considers man made and pumped canals which are costly. Hence these are to be avoided and so the original programme minimized pumpage cost for canal flow. In certain systems e.g., Bhakra Beas System, diversion may be preferable because of an existing high head reservoir and resultant flow through an additional power plant. Further more the unit cost of flow in the river reach and canal were taken as one in both the cases. In the revised programme, the cost of the river reach is kept as one while for the canal it is ten and the programme was modified so that it may not

minimize canal diversion. This requires identification of some river reaches where diversion is undesirable as canals and vice versa.

3.4.3 System state

The operation of the system depends upon whether storage and inflow in a given month indicate the water available to be below, at or above average conditions referred to respectively as dry, average and wet states. The states are determined as follows :

A specific group of reservoirs are used to identify the system state.

Let

S_i' = capacity of the i^{th} reservoir

N = number of reservoirs used in identifying the state of the system

$\leq$ the number of reservoirs in the system

t = the period under consideration

$X_{i,t}$ = end-of-month storage for the i^{th} reservoir in the t th time frame

$Y_{i,t+1}$ = Unregulated inflows to the i^{th} reservoir in the (t +1)th time frame

W = total storage capacity of reservoirs defining the state

$$= \sum_{i=1}^{N} S_i'$$

$$R = \sum_{i=1}^{N} X_{i,t} + \sum_{i=1}^{N} Y_{i,t+1} \qquad \ldots \qquad (3.1)$$

Let X_1 and X_2 be fractions of the subsystem maximum capacity used to determine the limits of the hydrologic state with $X_1 \leq X_2$. Define

$$L_B = X_1 W \text{ and}$$
$$U_B = X_2 . W$$

where the hydrologic state is determined by

$$R < L_B \qquad = \qquad \text{DRY}$$

$$L_B \leq R \leq U_B \qquad = \qquad \text{AVERAGE} \text{ , and}$$

$$R > U_B \qquad = \qquad \text{WET}$$

Associated with each one of these hydrologic states there is a corresponding set of operating rules and ranking priorities for meeting demands.

Based on input parameters supplied by the user for the operation of reservoirs and priorities, the programme optimises the reservoir releases.

In SIMYLD-II the decision about the states were made monthly but in India with a highly seasonal inflow, the state of the system does not generally vary in the non-monsoon season. For example the decision concerning the Bhakra Beas System are generally modified month after month (or every ten days) in the filling season but may be considered as constant in the nonfilling season. Hence the programme

has been modified to define and evaluate the state in the months of June, July, August and September and use the state in September for all subsequent months until next June.

As rule curve values change from month to month, it was necessary to define W in terms of desired storage in an average year rather than the total storage. Hence W was redefined as

$$W = \sum_{i=1}^{N} S_{i,t} \quad \text{where } S_{i,t} \text{ is the desired storage}$$

for ith reservoir in t^{th} time period for an average year as per the rule curve.

3.4.4 Energy

SIMYLD-II programme was developed to consider the demand for water, say for irrigation, water supply, etc. While irrigation is the major purpose of Beas Sutlej system, the energy needs are also important and it is necessary to keep track of the energy generation from month to month as well as seasonal and annual deficits in energy. Subroutine ENERGY is added to suit the specific requirement of the Beas Sutlej system and using the specific ' Elevation-Efficiency - Storage ' relationship of the system. It may be noted that for other systems the subroutines will need modification.

3.5. Details of Results from the Computer Programme

The output from SIMYLD II consists of three subreports as follows :

Sub-Report 1

This sub-report contains the information supplied by the user for the simulation and includes the number and description of the nodes, links and configuration of the system.

Sub-Report 2

This sub-report gives details informations on the nodes and links on the monthly basis and this includes initial storage, unregulated inflow, upstream spills, demand, surface area, evaporation rates, evporation losses, downstream spills, shortages, pumped into, pumped out, system loss, end of month storage and operating rules for each storage reservoir, demand, storage, and unregulated inflow for each non-storage nodes, and actual flows in each link and the annual average. This is repeated for every year.

Sub-Report 3

This sub-report provides a series of summaries the period of simulation and also for every year of simulation for each node and for each link.

3.6 Conclusion

It is possible to implement the original SIMYLD-II in IBM-7044 system and adapt the programme suitably though modifications and additions in order that Bhakra Beas System can be simulated. Final results considered in Chapter-4 indicate that further modifications should be made in the programme in order that it is more realistic. However the experience with SIMYLD-II indicates that when a large number of computer programmes are available for simulation of water resource systems, it may be easier to adapt some of the existing programmes than to write a new programme particularly when the systems are complex and not well understood.

4. SIMULATION OF BEAS SUTLEJ SYSTEM

4.1 System Description (Bhalla and Bansal, 1975, ,Mehindiratta and Hoon ,1973 a, Harbans Singh, 1964; BBDO, 1964).

The Beas Sutlej system (Shown in Fig. 4.1) has been chosen for the study. The river Sutlej, which originates in the regions of Mansrover in Tibet, enters Indian territory near Shipki and after flowing for a length of about 200 miles, it emerges in the plains of Punjab at Bhakra. Total catchment area of Sutlej above Bhakra Dam is about 21,960 sq.miles and of this 14,305 sq.miles lie in Tibet and only 7655 sq.miles lie in India.

The Sutlej catchment is affected by summer rainfall as well as winter rainfall. The period of south west monsoon rainfall extends from June to September, and winter rainfall extends from December to February. Rainfall in the catchment varies over the basin with an annual average of around 875 mm. Govindsagar, the reservoir formed by the Bhakra dam has a gross capacity of 7.644 m.a.f. and a live storage capacity of 5.932 m.a.f. above a dead storage of 1462 ft. It covers an area of 41,000 acres. The total runoff at Bhakra for a dependable year works out to 11.128 m.a.f. and that for a mean year to 13.329 m.a.f.

Water from Govindsagar can be passed through turbines of two power houses, one on the right bank and the other on the left bank at the foot of the Bhakra dam. Both the power

houses have 5 turbines each. Each of the generators in the right bank power house has a maximum capacity of 120 M.W.whereas each of the left bank generators has a maximum capacity of 90 M.W.

About 11 kms. downstream of Bhakra dam is Nangal reservoir formed by the 95 ft. high Nangal Dam. Part of the water from Nangal is released to Nangal hydel channel with a length of 40.07 miles and a carrying capacity of 12,633 cusecs. The remainder of the water is released to Sutlej. The Nangal hydel channel supplies water to two power houses on its path at Ganguwal and Kotla with a total installed capacity of 154 M.W. Water from the Nangal hydel channel is then divided between the Bhakra main canal and the Sirhind Canal.

Downstream of Nangal, there are head works at two places on the river Sutlej at Rupar and Harike. At Rupar water is diverted to Bist Doab and Sirhind Canals.

The Beas river takes off from the lower ranges of Shiwaliks and joins the river Sutlej at Harike. The total length of its course upto its confluence with River Sutlej is about 247 miles and the length upto Beas Dam at Pong is 143 miles. The catchment area of river Beas upto Pong is approximately 4,850 sq.miles. The average rainfall in the catchment is 1,778 mm. For a mean year the discharge at Mandi Plain varies from 5,328 cusecs minimum in the dry season to 65,350 cusecs during monsoon, with an annual average runoff of

13.01 m.a.f. For a dependable year, the runoff is 10.00 m.a.f.

Beas project has been undertaken for harnessing the water and power resources of the Beas river by means of storage and diversion works. It consists of (i) Beas-Sutlej link, which comprises a diversion dam at Pandoh across the Beas in the Kulu Valley to transfer 3.83 m.a.f. of water to the Bhakra reservoir through tunnels and open conduits capable of passing a maximum discharge of 7500 cusecs and (ii) Pong dam which provides for a storage dam at Pong with a maximum height of 432 ft, a gross storage of 6.952 m.a.f. and a live storage capacity of 5.908 m.a.f. The power plant has 4 units with an installed capacity of 60 M.W. each with provision for two additional units in future. The water released from Pong dam and utilised for generation of power will be used for irrigation through the Beas Canal system from the Harike head works. Water from the Ravi river is transferred by diversion at Madhopur head works through Madhopur Beas link (maximum capacity 10,000 cusecs) to the Beas river. This can be diverted at Harike to irrigate Beas command. The interconnected system of the Beas, Sutlej and Ravi rivers is shown in Fig. 4.1.

4.2 Node Link Representation of Bhakra-Beas System

For the consideration of the study the Beas-Sutlej system may be considered to consist of the following :

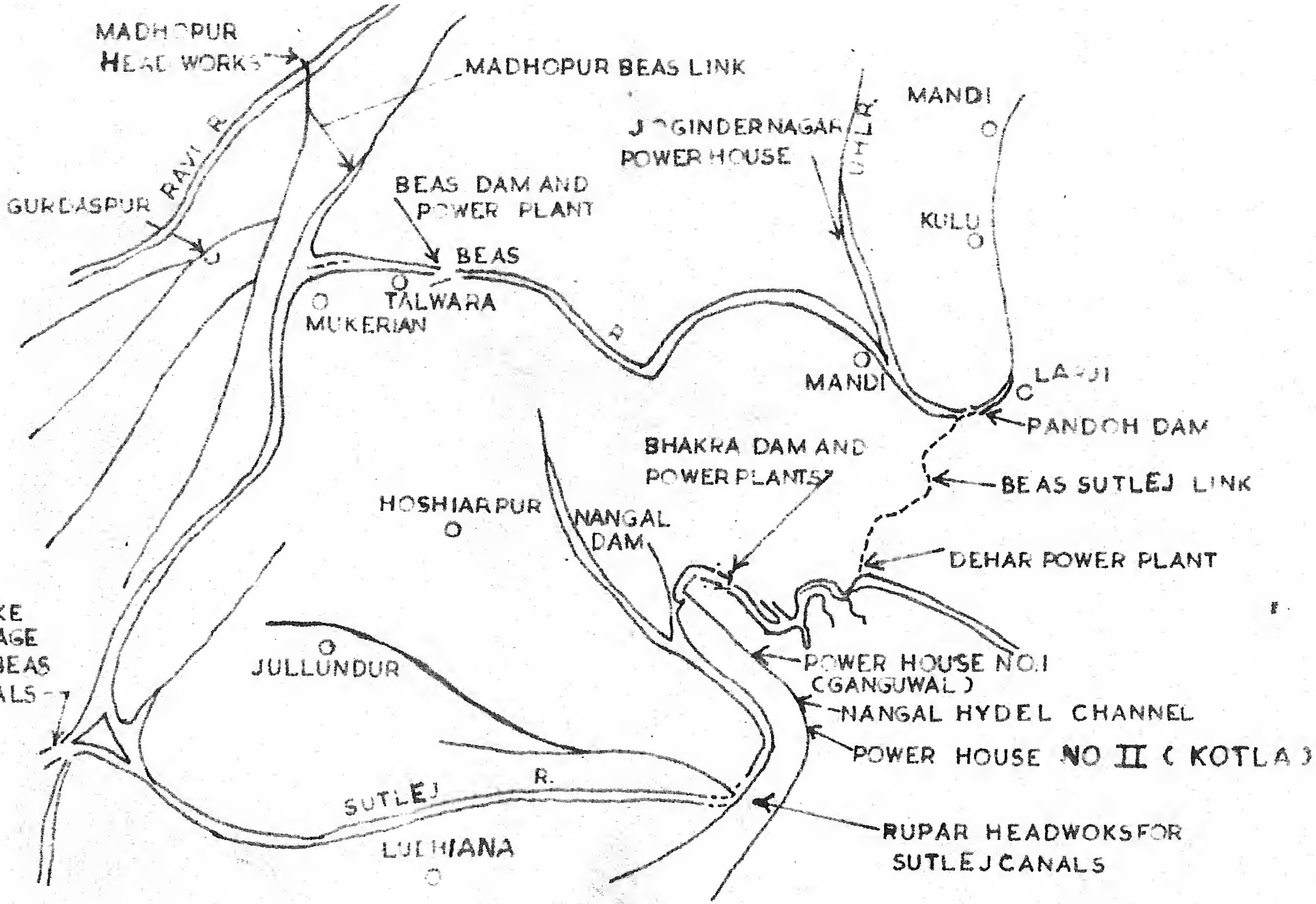


FIG. 4.1 INTER CONNECTED SYSTEM OF RIVERS RAVI, BEAS AND SUTLEJ
(BHALLA AND BANSAL 1975)

Two reservoirs at Bhakra (1) and Pong (2) and diversion point without storage at Pandoh (3) and five control points without storage at Dehar (4), Nangal (5), Rupar (6), Harike(7) and Mukerian (8). It may be noted that Nangal reservoir has a small storage capacity with reference to releases in a month and it is used for within the week and within the day balancing of demand and inflow. Hence the fluctuation of storage at Nangal is ignored in the study, and Nangal is treated as a control point without storage.

The number within the brackets is the serial number of the node with reservoir numbered first and other nodes later. The numbering of the river reaches and canals were done initially by treating the diversion canal as a canal and river reaches as river reaches. However because of the formulation of the original programme which minimises canal diversion, this formulation resulted in large diversion through Pong and small diversion through Dehar and Bhakra.

The inflow in river Beas may be diverted through Beas-Sutlej link for augumenting storage at Bhakra and hence to generate power at Dehar and Bhakra or permit to flow through Beas river to Pong, but diversion is always preferable and so flow from Pandoh to Pong is desirable only if the inflow at Pandoh is larger than the capacity of Beas-Sutlej link canal or when there is no storage available in Bhakra. Hence for the system model used in the study, Beas-Sutlej link is considered

as a river reach with a high priority and Beas river between Pandoh and Pong is considered as a canal section with a low priority and is numbered last as shown in Fig. 4.2.

4.3 Data Used in Simulation Analysis

Simulation analysis of Bhakra Beas system needs extensive details of data concerning the reservoir, canals, power houses, demands, inflow and priorities. Those have been obtained from Bhakra Beas Management Board (BBMB) and from a number of publications (BBDO, 1964) and include the water power studies of BBMB for cycle point 1921-22 to 1959-60. A brief description of the data used in the study are given in the following subsection.

4.3.1. Irrigation demand

The irrigated area served consists of parts of Punjab, Haryana and Rajasthan. The main crops grown in this region are bajra, cotton, maize, rice, jowar, sugarcane, oil seeds, pulses, potatoes and fodder during rabi season.

Beas Design Organization (B.D.O.) has estimated the demands for various command areas of the Beas-Sutlej system for dry, dependable and average years. A part of the demand is met from outside the basin including western Jamuna canal and the planned operation of the system for dry, dependable and average years are given in Tables 4.1, 4.2 and 4.3.

The requirements are low in the months from December to April except in the latter half of February and in March

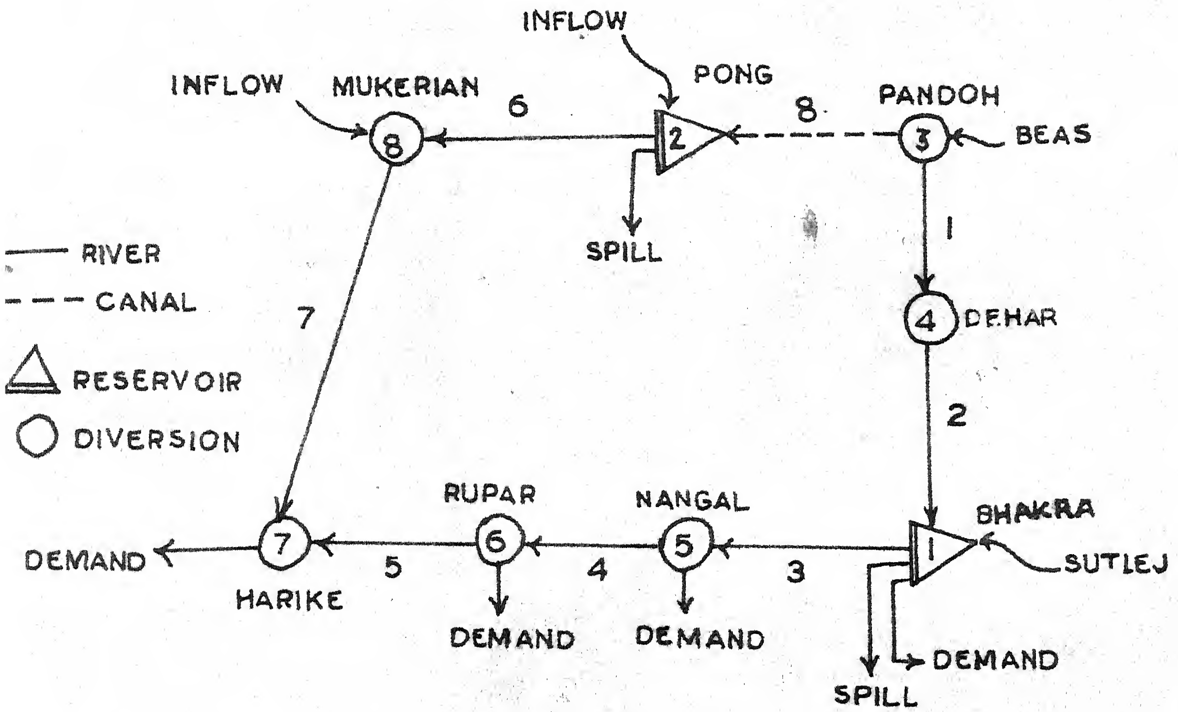


FIG. 4.2 NODE LINK REPRESENTATION OF BHAKRA BEAS SYSTEM

when water is required for maturing of rabi crops. The requirements are high in the months from September to November owing to water required for maturing of Kharif crops and preparation and sowing of Rabi crops. Rabi crop requirements are less than Kharif crop requirements. In the months of May and June, the requirements are again high due to preparation and sowing of Kharif crops. In the monsoon season also the requirements are quite high as the areas where such water is to be utilized, have low rainfall.

In the absence of additional prior information, the year is identified in this study as dry, dependable or average and the net corresponding B.D.O. demands were used in simulation analysis.

4.3.2 Power demand

The releases from the reservoir were originally planned to be made mainly in the interest of irrigation. Water is released in the interest of power from Bhakra reservoir only. These releases were to be in addition to those made in the interest of irrigation. Only 0.154 m.a.f. was earmarked for releases to be made to firm up power generation from Bhakra for average year while 1.084 m.a.f. and 1.099 m.a.f. was planned to be released in the interest of power for dry and dependable years respectively. The details of releases in the interest of power are also given in Tables 4.1 to 4.3.

4.3.3. Inflow data

The Beas-Sutlej system receives inflows from Sutlej at Bhakra, from Beas at Pandoh and Pong, and from Ravi-Beas diversion and Beas inflows at Mukerian. Inflow data for river Sutlej at Bhakra and for river Beas at Pandoh and Pong are available for ten daily periods for a large number of years.

In this study monthly data for only 13 years from June 1961 to May 1974 were used to derive the Sutlej inflow at Bhakra, Beas inflow at Pandoh and the additional inflow between Pandoh and Pong lumped as Pong inflows.

Rivers Ravi and Beas are interlinked through M.B.link of 10,000 cs capacity. B.D.O. recommended inflow at Mukerian through M.B. link for dry and dependable years as 1.442 m.a.f. and for the average year as 1.949 m.a.f. Details for monthly values are shown in Tables 4.1 to 4.3.

4.3.4. Evaporation rates

Evaporation occurs from the reservoir, channels and irrigation areas. Evaporation from irrigated areas is included in irrigation demands, but the losses from reservoir storage due to evaporation constitute a consumptive use and are not available for other uses. Hence they are to be estimated for Bhakra and Pong reservoirs. Mehndiratta and Hoon (1973) measured the pan evaporation at Bhakra from April 1966 to March 1971 and estimated the evaporation rates from inflow, outflow and storage data. They estimated an average pan

TABLE 4·1, WATER POWER STUDY FOR DRY YEAR

←DEHAR POWER PLANT→

Period	Inflow of River Beas at Pandoh for diversion to B.S.L. (CS)	Supply diverted through B.S.L. limited to 7500 CS 'Q'	Tailrace Elevation (ft)	Gross head available (2760 – Col. 4) (ft)	Head loss in tunnel 0.762 × 10⁻⁶ × Q2 (ft)	Head loss in Penstock (ft)	Total head loss (ft)		Mean head (ft) 2760 – Col. 8 – average tailrace Elevation 'H'	Efficiency 'e'	Power in M.W $\frac{Q.H.e}{11800}$	Inflow of River Beas at Pong (CS)	Supply diverted to B.S.L as in Col 3 (CS)	Inflow of River Beas at Pong after diversion at Pandoh (Col 13 – Col 14)	Requirements of Punjab Canals at Harike (CS)
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	–														
July	18827	7500	1650	↑	43	25	68		1042	↑	530	28314	7500	20814	7007
August	15[illegible]31	7500	1650		43	25	68		1042		530	22007	7500	14507	7007
Sept 1-10	115[illegible]	7500	1650		43	25	68		1042		530	18120	7500	10620	7154
11-20	9[illegible]4	7500	1650		43	25	68		1042		530	13590	7500	6090	7154
Sept 21-30	6326	6326	1650		30	22	52		1058		455	11018	6326	4692	7154
Oct.	4450	4450	1650		15	16	31		1079		327	7684	4450	3234	4602
Nov.	3113	3113	1650		7	15	22		1068		230	4756	3113	1643	4602
Dec.	2175	2175	1650	1110	4	15	19		1091	0.8	161	3715	2175	1540	3217
Jan.	1796	1796	1650		2	15	17		1093		133	2622	1796	826	2557
Feb.	1928	1928	1650		3	15	18		1092		143	3193	1928	1265	3379
Mar.	2809	2809	1650		6	15	21		1089		208	4108	2809	1299	3835
Apr.	3519	3519	1650		9	15	24		1086		260	4194	3519	675	3469
May	7144	7144	1650		39	24	63		1047		509	8090	7144	946	6790
June 1-10	9440	7500	1650		43	25	68		1042		530	11680	7500	4180	6790
11-20	11484	7500	1650		43	25	68		1042		530	12611	7500	5111	6790
21-30	16634	7500	1650	↓	43	25	68		1042	↓	530	15118	7500	7618	6790
M.A.F		3.611										7.104		3.653	3.681

RIVER BEAS

Supply delivered to Punjab Canals at Harike after applying RF during depletion period at 50% (CS)	Requirement of Rajasthan canals at Harike (CS)	Supply delivered to Raj. Canals at Harike after applying R.F. during depletion period at 38% (CS)	Total supply to Punjab & Raj. Canals at Harike (Col.17+Col.19) (CS)	Releases made at Bhakra for Harike needs (CS) (Col. 19 of Sheet 2)	Losses between Bhakra & Harike (CS)	Net Supplies delivered at Harike from Bhakra (Col.21-Col.22) (CS)	Net Supply available through M.B. Link at Harike (CS)	Releases made in the interest of Power (CS)	Gain or loss between Pong & Mandi Plain (CS)	Total releases at Pong Col.20-(Col.23+Col.24)+Col.26 (CS)	Storage or with drawal in cusecs	Storage or with drawal in thousand acre feet (T.A.F)	Losses in Pong Reservoir in acre feet	Net Storage in Pong Reservoir in T.A.F	Reservoir Elevation (ft.)	Tailrace Elevation (ft.)	Gross head (ft.) (Col 32-Col 33)
17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
				-	–	–	–	-	-	–	–	–	–	1044	1260	–	–
7007	15140	13140	20147	–	–	–	9000	–	+1500	9647	+11167	+692	15000	1721	1289	1088	201
7007	15140	13140	20147	–	–	–	9000	–	+1500	9647	+4860	+301	15000	2007	1298	1088	210
5523	14835	12083	17606	6453	–	6453	24	–	+1500	10370	+250	+5	5000	2007	1298	1088	210
3577	[illegible]	6451	10028	–	–	–	–	-	+1500	8528	-2438	-49	5000	1953	1297	1087	210
6577	21920	5064	11641	-	–	–	–	–	+1500	10141	-5449	-109	5000	1839	1293	1088	205
2301	[illegible]	7061	9362	–	–	–	–		+2000	9362	-5128	-318	13500	1508	1281	1087	194
2301	12780	4856	7157	-	–		–	-	+500	6657	-5014	-301	10500	1197	1268	1087	181
1608	8670	3371	4979	3341	668	2673	–	-	+500	1806	-260	-16	10500	1170	1266	1085	181
1278	8660	3291	4569	2721	148	2573	–	–	+500	1496	-670	-42	10500	1118	1264	1085	179
1689	9400	3572	5261	3429	–	3429	–	–	+500	1332	-67	-4	10500	1104	1263	1085	178
1917	14526	5520	7437	5048	–	5048	–	–	+500	1899	-600	-37	13000	1054	1261	1085	176
1734	5800	2204	3938	1726	–	1726	2212	–	–	–	+675	+40	15000	1079	1262	1085	177
3395	7552	2870	6265	5611	–	5611	453	–	-500	1268	-322	-20	15000	1044	1260	1085	175
4074	15126	8017	12091	7294	–	7294	1367	–	+500	3930	+250	+5	5000	1044	1260	1085	175
4700	15398	11935	16635	10241	–	10241	2033	–	+500	4861	+250	+5	5000	1044	1260	1086	174
5200	16398	12542	17742	8896	–	8896	2477	–	[illegible]	7269	+349	+7	5000	1046	1260	1087	173
	8.859				0.051		1.442		+0.212				0.093				

CS = cusecs M.A.F = Million Acre Feet T.A.F = Th

Losses in Penstock (ft)	Net head (ft.)	Mean head (ft.) 'H'	Efficiency (e).	Power in M.W Q.H.e/11800	Period
35	36	37	38	39	40
—	—	—	—	—	—
10	191	179.0	0.83	122	July
10	200	195.5	0.84	135	Aug
10	200	200.0	0.85	150	Sept. 1-10
8	202	201.0	0.85	124	11-20
10	195	198.5	0.85	145	Sept 21-30
8	186	190.5	0.84	114	Oct.
6	175	180.5	0.83	85	Nov.
6	175	175.0	0.82	22	Dec.
6	173	174.0	0.82	18	Jan.
6	172	172.5	0.81	16	Feb.
6	170	171.0	0.81	22	Mar.
6	171	170.5	0.81	—	Apr
6	169	170.0	0.81	15	May.
6	169	169.0	0.81	46	June 1-10
6	168	168.5	0.81	56	11-20
6	167	167.5	0.81	84	21-30
					M A.F.

ousand Acre Feet

Contd--Sheet 1 of 1

BHAKRA

Period	Inflow in River Sutlej at Bhakra (CS)	Supplies diverted through BSL limited to 7500 CS (Col.7 of Sheet 1 of 3)	Total inflow at Bhakra (CS) (Col.2 + Col.3)	Requirements of Rajasthan canals at Rupar (CS)	Supplies delivered to Raj canals after applying Res. factor during depletion period @ 38% (CS)	Delhi drinking water supplying (CS)	Total requirements of Punjab canals at Rupar (CS)	Supplies delivered to Pb. canals after applying Res. factor during depletion period @ 50% (CS)	Total Supplies delivered to both Rajasthan and Punjab canals at Rupar (CS) (Col.6+Col.7+Col.9)	Contribution from Jamuna (CS)	Gain or loss between Bhakra and Rupar (CS)	Releases made at Bhakra for Rupar canals {Col.10-(Col.11+Col.12)} (CS)	Supplies released at Bhakra for Harike canals (CS)	Releases in the interest of Power (CS)	Total releases made at Bhakra (Col.13+Col.14+Col.15) (CS)
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
JULY	37430	7500	44930	420	420	325	22493	22493	23238	2067	+1000	20171	-	-	20171
AUG.	36658	7500	44158	420	420	325	22493	22493	23238	3595	+1000	18643	-	-	18643
SEP. 1-10	24305	7500	31805	540	432	325	26355	21084	21516	1615	-	19901	6453	-	26354
11-20	14661	7500	22161	540	205	325	26355	13177	13707	-	-	13707	-	-	13707
SEP. 21-30	11301	6326	17627	540	205	325	26355	13177	13707	-	-	13707	-	-	13707
OCT.	6513	4450	10963	480	182	325	26624	13312	13819	-	-	13819	-	-	13819
NOV.	4597	3113	7710	480	182	325	24043	12021	12528	-	-	12538	-	-	12538
DEC.	3808	2175	5983	336	128	325	16421	8210	8663	-	+ 100	8563	3341	1540	13444
JAN.	3272	1796	5068	270	103	325	13261	6630	7058	-	+ 200	6858	2721	5881	15460
FEB.	2980	1928	4908	366	139	325	17708	8854	9318	-	+ 400	8918	3429	4165	16512
MAR.	3345	2809	6154	420	160	325	20056	10028	10513	-	+ 200	10313	5048	-	15361
APR.	4683	3519	8202	300	114	325	13088	6544	6983	-	- 300	7283	1726	6520	15529
MAY	10409	7144	17553	480	182	325	26068	13034	13541	-	- 600	14141	5611	-	19752
JUNE 1-10	16154	7500	23654	480	182	325	26499	13250	13757	-	- 600	14357	7294	-	21651
11-20	18566	7500	26066	480	480	325	26499	15900	16705	-	- 600	17305	10241	-	27546
21-30	29300	7500	36800	480	480	325	26499	26499	27304	-	- 600	27904	8896	-	36800
M.A.F	9.299	3.611	12.910	0.304			15.533			0.384	0.086			1.08	

CS = Cusecs

Storage or withdrawal in Cusecs (Col. 4 - Col. 16)	Storage or withdrawal in T.A.F.	Losses in Reservoir (acre feet)	Net Storage in T.A.F.	Reservoir Elevation (ft)	Tailrace Elevation (ft.)		Mean Head (ft) (H)	Net Head (ft) (Col. 24 - 4)	Efficiency (e)	Power in M.W. at Bhakra Q.H.e/11800	Power at Dehar Power Plant (Col. 12 of Sheet 1 of 2) (M.W.)	Power at Pong Power Plant (Col. 39 of Sheet 1 of 2) (M.W.)	Power at Nangal Canal Power Houses (M.W.)	Total	Period
17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
			1699	1462											
+24759	+1532	10000	3221	1550	1174		332.0	328.0	0.82	452	530	122		1258	July
+25515	+1580	10000	4791	1612	1173		408.0	404.0	0.84	535	530	135		1354	Aug.
+5451	+109	4000	4896	1615	1176		437.5	433.5	0.85	825	530	150		1659	Sept. 1-10
+8454	+169	3000	5062	1621	1171		447.0	443.0	0.85	439	530	124		1247	11-20
+3920	+78	3000	5137	1623	1171		451.0	447.0	0.85	443	455	145		1197	Sept 21-30
-2856	-177	8000	4952	1617	1171		449.0	445.0	0.85	444	327	114		1039	Oct.
-4828	-290	6000	4656	1607	1171		441.0	437.0	0.85	396	230	85		865	Nov.
-7461	-463	6000	4187	1590	1171		427.5	423.5	0.85	411	161	22		748	Dec.
-10392	-644	6000	3537	1564	1172		405.0	401.0	0.84	443	133	18		748	Jan.
-11604	-650	6000	2881	1534	1172		377.0	373.0	0.83	435	143	16	154 M.W	748	Feb.
-9307	-577	8000	2296	1503	1172		346.5	342.5	0.82	367	208	22		751	Mar.
-7327	-440	10000	1846	1473	1172		316.0	312.0	0.81	334	260	-		748	Apr.
-2199	-136	10000	1700	1462	1174		293.5	289.5	0.80	391	509	15		1069	May
+2003	+40	4000	1736	1465	1174		291.0	287.0	0.80	423	530	46		1153	June 1-10
-1480	-30	3000	1703	1462	1176		286.0	282.0	0.80	528	530	56		1268	11-20
-	-	3000	1700	1462	1179		283.0	279.0	0.80	698	530	84		1466	21-30

M.A.F. = Million Acre Feet.

T.A.F. = Thousand Acre Feet.

TABLE 4.2 WATER POWER STUDY FOR DEPNDABLE YEAR

DEHAR POWER PLANT

PERIOD	INFLOW OF RIVER BEAS AT PANDOH FOR DIVERSION TO B.S.L. (CS)	SUPPLY DIVERTED THROUGH B.S.L. LIMITED TO 7500 CS	TAILRACE ELEVATION (ft)	GROSS HEAD AVAILABLE (2760 – COL. 4) (ft)	HEAD LOSS IN TUNNEL $0.762 \times 10^{-6} \times Q^2$ (ft)	HEAD LOSS IN PEN STOCK (ft)	TOTAL HEAD LOSS (ft)	NET HEAD (ft) COL 5 – COL 8	MEAN HEAD (FT) 2760 – COL 8 – AVERAGE TAIL RACE ELEVATION	EFFICIENCY (e)	POWER IN M.W. Q.H.E. / 11800	INFLOW OF RIVER BEAS AT PONG (CS)	SUPPLY DIVERTED TO B.S.L. AS IN COL. 3 (CS)	INFLOW OF RIVER BEAS AT PONG AFTER DIVERSION AT PANDOH (COL. 13 – COL. 14)	REQUIREMENT OF PUNJAB CANALS AT HARIKE (CS)
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
JULY	20087	7500	1650	1110	43	[illegible]	68	1042	1042		530	30[illegible]4	7500	2344[illegible]	7[illegible]07
AUG.	21938	7500	1650	1110	43	25	68	1042	1042		530	50224	7500	42724	[illegible]
SEP 1-10	14520	7500	1650	1110	43	[illegible]	68	1042	1042		530	[illegible]1840	7500	24340	7154
11-20	11180	7500	1654	1106	43	25	68	103[illegible]	[illegible]		529	[illegible]	7500	13951	7154
SEP 21-30	8857	7500	1655	1105	43	25	68	1037	1037		527	13926	7500	6426	7154
OCT.	5040	5040	1650	1110	19	18	37	1073	1070.5		366	8055	5040	3015	4602
NOV.	2667	2667	1650	1110	5	15	20	1090	1090		197	4743	2667	2076	4602
DEC.	2111	2111	1650	1110	3	15	18	1092	1092		157	4108	2111	1997	3217
										0.8					
JAN	1912	1912	1650	1110	3	15	18	1092	1092		142	3939	1912	2027	2557
FEB	1956	1956	1650	1110	3	15	18	1092	1092		145	4133	1956	2177	3379
MAR	2930	2930	1650	1110	7	15	22	1088	1088		216	5065	2930	2135	3835
APR	5194	5194	1650	1110	21	18	39	1071	1071		379	6837	5199	1638	3469
MAY	7564	7500	1650	1110	43	25	68	1042	1042		530	9326	7500	1826	6790
JUNE 1-10	9333	7500	1650	1110	43	25	68	1042	1042		530	10122	7500	2622	6790
11-20	10[illegible]72	7500	1650	1110	43	25	68	1042	1042		530	13231	7500	5731	6790
21-30	13866	7500	1650	1110	43	25	68	1042	1042		530	15363	7500	7863	6790
M.A.F.	5.77	3.62										9.97		6.35	3.68

RIVER BEAS

[illegible] diverted to Punjab canals at Harike after applying R.F. during depletion period [illegible]	Requirements of Punjab canals at Harike CS	[illegible] diverted [illegible] canals at Harike [illegible]	[illegible]	[illegible] Bhakra [illegible] Harike canals (CS) [illegible]	CS [illegible] Bhakra & Harike	[illegible] at Harike from Bhakra (Col 21 [illegible] 22)	Net supply available through [illegible] at Harike (CS)	[illegible] in interest of power	Gain/loss between Pong & [illegible] plain (CS)	Total releases at Pong (Col 20 [illegible] Col 24 + Col 26) (CS)	Storage or withdrawal in cusecs	Storage or withdrawal in thousand acre feet (T.A.F.)	Losses in Pong reservoir in acre feet	Net storage in Pong reservoir in T.A.F.	Reservoir elevation (FT)	Tailrace elevation (FT)	Gross head FT Col. 32 − Col. 33
17	18	[illegible]	20	[illegible]	22	[illegible]	24	[illegible]	[illegible]	[illegible]	[illegible]	29	30	[illegible]	[illegible]	[illegible]	[illegible]
?7	?14	[illegible]	[illegible]		—	—	?0?	—	[illegible]0	547?	?5??9	+8?6	15000	79	129?	1088	2?9
7?	[illegible]	1?10	?4	—	—	—	5?00	—	?500	?547	3307?	+2051?	15000	38?5	1343	1088	255
[illegible]	[illegible]	[illegible]	[illegible]		—		241?	—	+15?0	15?	5?	+12?	5000	3?46	1345	1?9	254
[illegible]	15?	?5?	5?		—	-	[illegible]		?800?	1446?	−516	?10	[illegible]	395?	1344	105?	254
5001	?122	135?4	136?5			—	− −	—	−1500	17195?	−1076?	−215	5000	3711	1340?	109?	249
324?	18582	1??18	15??		− −	—	—	—	+1000	14197	−11182	−693	13500	3004	1325	1090	235
32?9	1278?	821	145?	—	—	—	—	—	+500	1?966	−8890	−533	10500	2460	1313	1088	225
22??	?870	57?3	7973	3341	668	2673	—	− −	+500	4800	−2803	−174	10500	2276	1308	1086	222
1805	?5?0	55?8	7373	2221	148	2073	—	—	+500	4800	−2773	−172	10500	2093	1304	1086	218
2385	?400	?044	8429	3129	—	3?2?	—	—	+500	4800	−2623	−147	10500	1?36	1300	1086	214
2708	14525	9340	12048	3048	—	3048	—	—	+500	8500	−6365	−395	13000	1528	1287	1087	200
2449	5800	3729	6178	2831	—	2831	2212	—	—	1135	+503	+30	15000	1543	1288	1085	203
4794	7552	4855	9650	—	—	− −	453	—	−500	9697	−7871	−488	15000	1040	1264	1088	176
4794	5126	9726	14520	6153	− −	[illegible]	1367	—	−500	7500	−4878	−98	5000	938	1260	1087	173
4895	15398	22?0	7?05	100?	—	70??	2033	—	−500	5481	+250	+5	5000	950	1260	1086	174
?534	153?8	3?0?	?33?4	??4?4	—	974?	?477	—	−500	7613	+250	+5	5000	950	1260	1087	173
	8.858				0.051		?.4?2		+0.428				0.003				

CS = CUSECS   M.A.F = MILLION ACRE FEET   T.A.F = THOUSAND ACRE FEET

LOSSES IN PENSTOCK (FT)	NET HEAD (FT)	MEAN HEAD (FT) H'	EFFICIENCY	POWER IN M.W. Q.H.E./11800	PERIOD
35	36	37	38	39	40
0	99	82.5	0.83	123	JULY
10	245	22[illegible]	0.85	153	AUG.
10	244	244.5	0.84	315	SEPT. 1-10
0	244	244.0	0.84	2[illegible]1	11-20
10	239	241.5	0.84	29[illegible]	SEP 21-30
10	225	232	0.84	234	OCT
10	215	220	0.85	173	NOV
6	216	215.5	0.85	75	DEC.
5	212	214	0.85	74	JAN
6	208	210	0.85	73	FAB.
8	192	200 0	0.85	12 3	MAR.
6	197	194.5	0.84	16	APR
10	166	181.5	0.83	124	MAY
6	167	167	0.81	36	JUN 1-10
6	168	168	0.81	64	11-20
7	166	167	0.81	87	21-30

BHAKRA

PERIOD	INFLOW IN RIVER SUTLEJ AT BHAKRA (CS)	SUPPLIES DIVERTED THROUGH B.S.L LIMITED TO 7500 CS (COL 3 OF SHEET 1 OF 2)	TOTAL INFLOW AT BHAKRA (COL 2 + COL 3) (CS)	REQUIREMENTS OF RAJASTHAN CANALS AT RUPAR (CS)	SUPPLIES DELIVERED AT RAJ. CANALS AFTER APPLYING RES. FACTOR DURING DEPLETION PERIOD @ 64.3 (CS)	DELHI DRINKING WATER SUPPLY (CS)	TOTAL REQUIREMENTS OF PUNJAB CANALS AT RUPAR (CS)	SUPPLIES DELIVERED TO PB. CANALS AFTER APPLYING RES. FACTOR DURING DEPLETION PERIOD @ 70.6 (CS)	TOTAL SUPPLIES DELIVERED TO BOTH RAJASTHAN AND PUNJAB CANALS AT RUPAR (CS) (COL 6 + COL 7 + COL 9)	CONTRIBUTION FROM JAMUNA (CS)	GAIN OR LOSS BETWEEN BHAKRA AND RUPAR (CS)	RELEASES MADE AT BHAKRA FOR RUPAR CANALS (COL 10 - (COL 11 + COL 12)) (CS)	SUPPLIES RELEASED AT BHAKRA FOR HARIKE CANALS (CS)	RELEASES IN THE INTEREST OF POWER (CS)	TOTAL RELEASES MADE AT BHAKRA (COL 13 + COL 14 + COL 15) (CS)
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
JULY	43557	7500	51057	420	420	325	22493	22493	23238	2067	+1000	[illegible]	—	—	20171
AUG.	45694	7500	53194	420	420	325	22493	[illegible]	23238	3595	+1000	[illegible]	—	—	18643
SEPT. 1-10	28997	7500	36497	540	540	325	26355	26355	27220	1615	—	[illegible]	—	—	25605
11-20	20559	7500	28059	540	347	325	26355	18607	19279	—	—	19279	—	—	19279
SEPT. 21-30	12930	7500	20430	540	347	325	26355	18607	19279	—	—	19279	—	—	19279
OCT.	8259	5040	13299	480	309	325	26624	18797	19431	—	—	19431	—	—	19431
NOV.	5432	2667	8099	480	309	325	24043	16974	17608	—	—	17608	—	—	17608
DEC.	4339	2111	6450	336	216	325	16421	11595	12136	—	+100	12036	334	1573	[illegible]
JAN.	3864	1912	5776	270	174	325	13261	9362	9861	—	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
FEB.	3841	1956	5797	366	235	325	17708	12502	13062	—	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
MAR.	4382	2930	7312	[illegible]	[illegible]	325	20056	[illegible]	14755		+200	[illegible]	[illegible]	[illegible]	[illegible]
APR.	5741	5199	10940	300	193	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	183	[illegible]	[illegible]
MAY	11100	7500	18600	[illegible]	309	325	26068	18404	19038	—	-600	19638	—	—	19638
JUNE 1-10	18516	7500	26016	480	309	325	26499	18708	19342	—	-600	19942	6153	—	26095
11-20	24985	7500	32485	480	480	325	26499	20859	21644	—	-600	22244	10091	—	32335
21-30	30298	7500	37798	480	480	325	26499	26499	27304		-600	27904	9744	—	37648
M.A.F	11.125	3.62	14.74	0.304	0.225	0.237	15.533	—	—	0.384	0.086	12.130		1.099	

CS = CUSECS   M.A.F. = MILLION ACRE FEET

(GS) STORAGE OR WITHDRAWAL IN CUSECS (COL.4 − COL.16)	STORAGE OR WITHDRAWAL IN ACRE FEET	LOSSES IN RESERVOIR (ACRE FEET)	NET STORAGE IN ACRE FEET	RESERVOIR ELEVATION (FEET)	TAILRACE ELEVATION (FEET)	GROSS HEAD (H)	NET HEAD (ft) (COL 23 − 4)	NET HEAD (ft) (H)	EFFICIENCY (E)	POWER IN M.W. AT BHAKRA QHE/11800	POWER AT DEHAR POWER PLANT (COL.12 OF SHEET 1 OF 2) (M.W.)	POWER AT PONG POWER PLANT (COL 39 OF SHEET 1 OF 2) (M.W)	POWER AT NANGAL CANAL POWER HOUSES (M.W)	TOTAL	PERIOD
17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
[illegible]66	+19,4932	[illegible]	[illegible]	[illegible]563	1170	393	[illegible]	[illegible]	[illegible]	471	[illegible]	[illegible]		1278	JULY
[illegible]	[illegible]	[illegible]	[illegible]94	1639	1170	[illegible]	[illegible]	[illegible]	0.85	[illegible]	[illegible]	[illegible]		1411	AUG.
[illegible]	+217840	[illegible]	[illegible]2434	1645	1172	473	[illegible]	467	0.84	[illegible]	[illegible]	[illegible]		[illegible]651	SEPT 1-10
[illegible]8[illegible]	[illegible]	[illegible]	[illegible]0.34	1649	1170	[illegible]	[illegible]	[illegible]	0.84	[illegible]	[illegible]	[illegible]		1581	11-20
+111[illegible]	+[illegible]	3000	[illegible]	1656	1170	480	476	[illegible]	[illegible]	[illegible]	52[illegible]	[illegible]		16[illegible]	SEPT. 21-30
6138	[illegible]84	8000	[illegible]	1639	1170	469	465	[illegible]	[illegible].84	[illegible]	366	[illegible]		[illegible]	OCT
[illegible]9509	[illegible]	6000	5450330	[illegible]	[illegible]	451	447	[illegible]	0.84	[illegible]	197	[illegible]73		1095	NOV.
−10500	−651000	6000	4793330	1593	[illegible]	430	426	435.5	0.85	534	[illegible]	[illegible]		920	DEC.
[illegible]	[illegible]5088	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.85	[illegible]	132	[illegible]	154 MW	920	JAN.
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]75	[illegible]	[illegible]	[illegible]	[illegible]		920	FEB.
−1[illegible]	[illegible]	8000	[illegible]	1494	[illegible]	[illegible]4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		920	MAR.
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2[illegible]4	[illegible]	[illegible]	[illegible]72	378	[illegible]		920	APR.
[illegible]	[illegible]	[illegible]	1594[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.80	[illegible]	530	124		[illegible]	MAY
[illegible]	[illegible]	[illegible]	19975[illegible]	[illegible]	[illegible]	[illegible]	285	[illegible]	0.80	509	530	86		[illegible]	JUNE 1-10
+[illegible]	+3000	3000	197150[illegible]	1462	[illegible]	[illegible]	282	284	0.80	[illegible]	530	54		[illegible]	11-20
+150	[illegible]3000	3000	1971500	1462	1175	[illegible]	283	283.5	0.80	[illegible]	530	[illegible]		[illegible]	21-30

T.A.F. = THOUSAND ACRE FEET

Sheet 2 of 2

TABLE 4.3 WATER POWER STUDY FOR AVER[illegible] YEAR

← DEHAR POWER PLANT →

Period	Inflow of River Beas at Pandoh for diversion to B.S.L (cs)	Supply diverted through B.S.L limited to 7500 cs (Q)	Tailrace Elevation (ft)	Gross head available (2760 - Col 4) (ft)	Head loss in tunnel 0.76 × 10⁻⁶ × Q² (ft)	Head loss in penstock (ft)	Total head loss (ft)	Net head (ft) (Col.5 - Col.8)	Mean head (ft) 2760 - Col.9 average tailrace Elevation 'H'	Efficiency 'e'	Power in MW QHe/11800	Inflow of River Beas at Pong (cs)	Supply diverted to B... as in Col 3 (cs)	Inflow of River Beas at Pong after diversion at Pandoh (Col.13 - Col.14)	Requirements of Punjab Canals at Harike (cs)
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
July	22341	7500	1650	1110	43	25	68	1042	1042		530	40202	7500	32702	7007
August	24400	7500	1675	1085	43	25	68	1017	1030		523	62120	7500	54620	7007
Sept 1-10	17058	7500	1684	1076	43	25	68	1008	1013		515	45862	7500	38362	7154
11-20	14081	7500	1687	1073	43	25	68	1005	1007		512	32845	7500	25345	7154
Sept 21-30	12072	7500	1688	1072	43	25	68	1004	1005		511	22345	7500	14845	7154
[illegible]	6454	6454	1673	1087	32	22	54	1033	1019		449	13049	6454	6595	4602
Nov	3077	3077	1650	1110	7	15	22	1088	1061	0·8	225	5831	3077	2754	4602
Dec.	2259	2259	1650	1110	4	15	19	1091	1091		167	4851	2259	2592	3217
Jan	2039	2039	1650	1110	3	15	18	1092	1092		151	5077	2039	3038	2557
Feb	2259	2259	1650	1110	4	15	19	1091	1091		167	5774	2259	3515	3379
Mar	3402	3402	1650	1110	9	15	24	1086	1086		250	6688	3402	3286	3835
Apr	5671	5671	1650	1110	25	20	45	1065	1065		410	8496	5671	2825	3469
May	8852	7500	1650	1110	43	25	68	1042	1042		530	10934	7500	3434	6790
June 1-10	11344	7500	1650	1110	43	25	68	1042	1042		530	13330	7500	5830	6790
11-20	12928	7500	1650	1110	43	25	68	1042	1042		530	14774	7500	7274	6790
21-30	16081	7500	1650	1110	43	25	68	1042	1042		530	19015	7500	11515	6790
M.A.F.	6.65	3.823										13.008		9.185	3.681

RIVER BEAS

[illegible] Canals at [illegible]	Requirement of [illegible] canals at Harike (CS)	Supply delivered to Raj Canals at Harike after applying R.F. during depletion as adding % (CS)	Total Supply to Punjab & Raj. canals at Harike Col.17+Col.19 (CS)	Releases made at Bhakra to Harike canals (CS) Col. 14 of Sheet 2 of 3	Losses between Bhakra & Harike (CS)	Net supplies delivered at Harike from Bhakra (Col 21-Col 22) (CS)	Net supply available through M.B. Link at Harike (CS)	Releases made in the interest of Power (CS)	Gain or loss between Pong & Mandi Plain (CS)	Total releases at Pong & Col 20-(Col 23+Col 24+Col. 26) (CS)	Storage or with drawal in Cusecs	Storage or with drawal in Thous. acre feet (T.A.F.)	Losses in Pong Reservoir in acre feet	Net Storage in Pong Reservoir in T.A.F.	Reservoir Elevation (ft)	Tailrace Elevation (ft)
17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33
7007	13140	13140	20147	–	–	–	9000	–	+2500	8647	+24055	+ 1491	15000	2426	1312	1087
[illegible]	13140	13140	20147	–	–	–	9000	–	+2500	8647	+45973	+ 2850	15000	5262	1372	1087
[illegible]	14854	14854	22008	–	–	–	6199	–	+2000	13809	+24553	+ 491	5000	5748	1383	1089
7154	15976	15976	24130	–	–	–	3199	–	+2000	18931	6414	+ 128	5000	5871	1388	1092
7154	21220	21220	28374	–	–	–	626	–	+2000	25748	-10903	- 218	5000	5648	1381	1094
4602	18582	18582	23184	–	–	–	–	–	+1000	22184	-15589	- 967	13500	4668	1360	1093
4602	[illegible]	11780	16382	–	–	–	–	–	+ 500	16882	-14128	- 848	10500	3810	1342	1091
3217	[illegible]	8870	12087	–	–	–	–	–	+ 500	11587	-8995	- 558	10500	3242	1330	1089
2557	8660	8660	11217	9094	1819	7275	–	–	+ 500	4442	+404	- 25	10500	3206	1329	1085
[illegible]	9400	9400	12719	2851	190	2661	–	–	+ 500	9618	-6103	+ 342	10500	2854	1322	1088
3835	14525	14525	18360	–	–	–	843	–	+ 500	17017	-13731	- 851	13000	1989	1303	1091
3469	5800	5800	9269	5612	–	5612	3657	–	–	–	+ 2825	+ 169	15000	2144	1306	1085
6790	7552	7552	14342		–	–	2128	–	- 500	12714	-9280	- 575	15000	1554	1288	1089
[illegible]	15724	15126	21916	–		–	2914	–	- 500	19502	-13672	- 273	5000	1275	1277	1092
5930	15398	13443	19373	9453	–	9453	3395	–	- 500	7024	+ 250	+ 5	5000	950	1260	1087
6790	15398	15398	22188	6255	–	6255	5168	–	- 500	11265	+ 250	+ 5	5000	950	1260	1088
	8.858				0.123		1.946		0.582				0.093			

CS = Cusecs

M.A.F = Million Acre Feet.

T.A.F. = Th

Gross head (ft) Col. 32 - Col. 33	Losses in Penstock (ft)	Net head (ft)	Mean head (ft) 'H'	Efficiency 'e'	Power in M.W Q.H.e/11800	Period
34	35	36	37	38	39	40
225	8	217	190	0·84	117	July
285	8	277	247	0·84	152	Aug
294	10	284	280	0·82	269	Sept 1-10
296	10	286	285	0·82	375	11-20
287	10	277	282	0·82	505	Sept 21-30
267	10	257	267	0·83	416	Oct.
251	10	241	249	0·84	300	Nov
241	10	231	236	0·84	194	Dec.
244	6	238	235	0·84	57	Jan
234	10	224	231	0·84	159	Feb
212	10	202	213	0·85	261	Mar.
221	—	221	211	0·85	—	Apr
199	10	189	265	0·85	188	May
185	10	175	182	0·83	250	June 1-10
173	6	167	177	0·81	83	11-20
172	10	162	164	0·81	127	21-30
						M.A.F

SUPPLIES RELEASED AT BHAKRA FOR HARIKE CANALS (CS)	RELEASES IN THE INTEREST OF POWER (CS)
14	15
—	—
—	—
—	—
—	—
—	—
—	—
—	—
—	—
9094	—
2851	—
—	—
5612	3575
—	—
—	—
9453	—
6255	—
	0·154

M. A. F = M

sand Acre Feet

TABLE 4.3 CONTD...

BHAKRA

PERIOD	INFLOW IN RIVER SUTLEJ AT BHAKRA (CS)	SUPPLIES DIVERTED THROUGH B.S.L. LIMITED TO 7500 CS (COL.3 OF SHEET I OF 3)	TOTAL INFLOW AT BHAKRA (COL 2 + COL 3)	REQUIREMENT OF RAJASTHAN CANALS AT RUPAR (CS)	SUPPLIES DELIVERED TO RAJ. CANALS AFTER APPLYING RES. FACTOR DURING DEPLETION PERIOD @100% (CS)	DELHI DRINKING WATER SUPPLYING (CS)	TOTAL REQUIRMENTS OF PUNJAB CANALS AT RUPAR (CS)	SUPPLIES DELIVERED TO Pb. CANAL AFTER APPLYING RES. FACTOR DURING DEPLETION PERIOD @100% (CS)	TOTAL SUPPLIES DELIVERED TO BOTH RAJASTHAN AN PUNJAB CANALS AT RUPAR (CS) (COL6+COL7+COL.9)	CONTRIBUTION FROM JAMUNA (CS)	GAIN OR LOSS BETWEEN BHAKRA AND RUPER (CS)	RELEASES MADE AT BHAKRA FOR RUPAR CANALS [(COL10-(COL11+COL12)]	SUPPLIES RELEASED AT BHAKRA FOR HARIKE CANALS (CS)	RELEASES IN THE INTEREST OF POWER (CS)
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
JULY	49981	7500	57481	420	420	325	22493	22493	23238	2201	+1500	19537	—	—
AUGUST	53263	7500	60763	420	420	325	22493	22493	23238	3595	+1500	18143	—	—
SEP. 1-10	33944	7500	41444	540	540	325	26355	26355	27220	4045	+ 500	22675	—	—
11-20	24909	7500	32409	540	540	325	26355	26355	27220	1615	+ 500	25105	—	—
SEP. 21-30	19246	7500	26746	540	540	325	26355	26355	27220	1517	+ 500	25203	—	—
OCT.	10878	6454	17332	480	480	325	26624	26624	27429	—	—	27429	—	—
NOV.	6208	3077	9285	480	480	325	24043	24043	24848	—	—	24848	—	—
DEC.	4738	2259	6997	336	336	325	16420	16420	17081	—	+ 100	16981	—	—
JAN.	4328	2039	6367	270	270	325	13261	13261	13856	—	+ 200	13656	9094	—
FEB.	4400	2259	6659	366	366	325	17708	17708	18399	—	+ 400	17999	2851	—
MAR.	4786	3402	8188	420	420	325	20056	20056	20801	—	+ 200	20601	—	—
APR.	6923	5671	12594	300	300	325	13088	13088	13713	—	- 300	14013	5612	2575
MAY	15472	7500	22972	480	480	325	26068	26068	26873	—	- 600	27473	—	—
JUNE 1-10	23910	7500	31410	480	480	325	26499	26499	27304	—	- 600	27904	—	—
11-20	30007	7500	37507	480	480	325	26499	26499	27304	—	- 600	27904	9453	—
21-30	38045	7500	45545	480	480	325	26499	26499	27304	—	-600	27904	6255	—
M.A.F.	13.329			0.304			15.533			0.503				0.154

CS = CUSECS M.A.F. = M

TOTAL RELEASES AT BHAKRA (Q) (COL13+COL14+COL15) (CS)	STORAGE OR WITHDRAWAL IN CUSECS (COL4 - COL16)	STORAGE OR WITHDRAWAL IN T.A.F. FEET	LOSSES IN RESERVOIR (ACRE FT)	NET STORAGE IN T.A.F.	RESERVOIR ELEVATION (FT)	TAILRACE ELEVATION (FT)	GROSS HEAD (FT)	NET HEAD (FT) (COL23-4')	MEAN HEAD (FT) (H)	EFFICIENCY (E)	POWER IN M.W. AT BHAKRA QHE/11800	POWER AT DEHAR POWER PLANT (M.W.)	POWER AT PONG POWER PLANT (M.W.) (COL 12 OF SHEET [illegible])	POWER AT NANGAL CANAL POWER HOUSES (M.W.)	TOTAL	PERIOD
16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
19537	37944	+2352	10000	4539	1590	1170	420	416	357	0.83	490	530	117	15.4 M.W.	1291	JULY
18143	42620	+2642	10000	7171	1610	1170	500	496	456	0.84	590	523	152		1419	AUGUST
22675	18769	+ 375	4000	7543	1679	1171	508	504	500	0.83	797	515	267		1735	SEP. 1-10
25105	7304	+ 146	3000	7686	1692	1172	510	506	505	0.83	891	512	375		1932	11-20
25203	1543	+ 30	3000	7714	1683	1172	511	507	507	0.83	900	511	505		2070	SEP. 21-30
27429	-10097	− 626	8000	[illegible]	1668	1173	495	491	499	0.83	963	449	416		1982	OCT.
24848	-1556	− 334	6000	6140	1642	1172	470	466	478	0.83	837	225	300		1516	NOV.
16981	−9954	− 619	5000	5515	1623	1169	454	450	458	0.84	553	167	194		1068	DEC.
22770	− 5343	− 1916	6000	4493	1588	1171	[illegible]7	413	431	0.85	706	151	[illegible]		1068	JAN.
20850	[illegible]	− 795	6000	3693	1555	1171	384	380	396	0.84	588	167	159		1068	FEB.
20601	−12413	− 770	8000	2914	1518	1171	347	343	361	0.83	523	250	261		1188	MAR.
22200	[illegible]	− 576	10000	2328	1485	[illegible]	314	310	326.5	0.82	501	410	—		1068	APR.
[illegible]	[illegible]	+ 2[illegible]9	10000	2039	1466	[illegible]73	293	289	299	0.80	557	530	188		1429	MAY
27904	+ 3516	+ 70	4000	2105	1470	1173	297	293	291	0.80	550	530	250		1484	JUNE 1-10
37357	+ 150	+ 3	3000	1972	1462	1175	287	283	288	0.80	729	530	83		1496	11-20
34159	11385	+ 227	3000	2196	1476	1174	302	298	291	0.80	673	530	127		1484	21-30
																M.A.F

...LLION ACRE FEET T.A.F = THOUSAND ACRE FEET

coefficient of 0.7 for Bhakra reservoir. Using meteorological data and normal meterological condition, the average monthly evaporation rates have been calculated. The average annual evaporation is around 5 ft. (4.80 ft) and the monthly values from June to May are 0.73, 0.43, 0.32, 0.39, 0.34, 0.25, 0.17 0.16, 0.21, 0.37, 0.63, 0.84 ft respectively. These evaporation rates were used for Pong reservoir also.

4.3.5 Elevation area capacity curves

Elevation area capacity relationships for Bhakra and Pong reservoirs were obtained in tabular and graphical form from B.D.O. and B.B.M.B. These were defined by sixteen matched points per reservoir and are shown in Table 4.4. For intermediate values linear interpolation was adopted. These data were used to define minimum storage, the maximum capacity of the reservoir and also the rule curve.

4.3.6 Data for energy generation

Power is generated in the system at Bhakra, Pong, Dehar and Nangal including Ganguwal and Kotla power houses. Rajendra Nagar and other small systems in tributaries are ignored in the study.

The energy generated at Nangal is assumed to be constant (154 MW) as in the B.D.O. studies. Dehar is a constant head power plant and hence the head and efficiency at Dehar are assumed as constant and energy generation are directly

TABLE 4.4 ELEVATION-AREA-CAPACITY OF BHAKRA AND PONG RESERVOIRS

Point	Bhakra Reservoir			Pong Reservoir		
	Elevation in Ft.	Area in Acres	Capacity in Acre Ft.	Elevation in Ft.	Area in Acres	Capacity in Acre Ft.
1	1400	9550	1037156	1260	19182	1044000
2	1420	9830	1232568	1270	22041	1250000
3	1440	11620	1448854	1280	25089	1484000
4	1460	11880	1685808	1290	28784	1754000
5	1480	14890	1955734	1300	32337	2060000
6	1500	15970	2266902	1310	35686	2402000
7	1520	18820	2617696	1320	38960	2776000
8	1540	20870	3017898	1330	42251	3180000
9	1560	23130	3461558	1340	45821	3620000
10	1580	25370	3950592	1350	49336	4096000
11	1600	28050	4489236	1360	52792	4606000
12	1620	30830	5082934	1370	55744	5150000
13	1640	34000	5736628	1380	58629	5722000
14	1660	37050	6453038	1390	61612	6324000
15	1680	40150	7231460	1400	64404	6952000
16	1700	43400	8074112	1410	67048	7610000

related to their discharge in Beas-Sutlej link.

For Bhakra and Pong reservoir, the head on the turbine depends upon the reservoir storage and downstream releases and the efficiency of the system depends upon the net heads and these vary from month to month. B.D.O. has considered the details of planned storage and releases for estimating the net head and efficiencies for dry, dependable and average years (Tables 4.1 to 4.3).

From a comparison of the heads, losses and efficiencies in dry, dependable and average years in the B.D.O. studies, it is concluded that, for the purpose of the study, head loss may be considered as constant equal to 4 ft and 8 ft for Bhakra and Pong power plants. Efficiencies may be considered to vary piecewise linearly as the function of the net head. The efficiency (η) net head(H) relationship adopted in this study are indicated in Table 4.5. It is possible to use a better procedure for estimating the energy generated more accurately.

4.3.7. Link capacities

The capacity of Beas Sutlej link is assumed to be 7500 cusecs in BBMB studies. The capacity of the river Sutlej and Beas are considered to 50,000 cusecs each. The lower limit for link flows is assumed to be zero.

TABLE 4.5 HEAD-EFFICIENCY RELATIONSHIPS

Bhakra Power Plant		Pong Power Plant	
Head Ft.	Efficiency	Head Ft.	Efficiency
Below 300	0.80	Below 170	0.81
300	0.80	170	0.81
325	0.81	180	0.83
350	0.82	190	0.84
375	0.83	200	0.85
400	0.84	215	0.85
425	0.85	241	0.838
450	0.84	267	0.826
475	0.83	280	0.82
above 475	0.83	above 280	0.82

4.4 Study of Planned Operation

4.4.1 Planned operation

The planned operation for dry, dependable and average years are given in Tables 4.1 to 4.3. It is proposed to study the planned operation of the system in order that the characteristic of the system can be understood and improvement can be made in the operation of the system. The following additional assumptions were made for studying the planned operation.

i) Only Bhakra is considered as spill reservoir, and

ii) The irrigation demands were initially taken as average year demands. However because the inflow in large number of years were much less than the average demand., it was decided to modify the demand in the 5th year as a dry year demand.

B.D.O. has suggested rule curves for dry, dependable and average years while the study required rule curves for dry, average and wet states. The rule curve for average and dry states were adopted from B.D.O. studies and rule curve for wet states was estimated from these two and used in the study. These are indicated in Table 4.6.

4.4.2. Value judgements

It is necessary to define the relative priorities between and among storages and demands. From a consideration of the characteristics of the system, the following general conclusions were derived :

i) Storage in Bhakra reservoir is much more valuable than in Pong reservoir because of its high head and its ability to supply irrigation water to all demand nodes;

ii) Demand at Nangal is more valuable than that of Rupar and Harike because of power generation benefits;

iii) Releases in the interest of power from Bhakra have a lower priority;

iv) Storage is more valuable in a dry year than in wet or average years; and

v) Diversion through Dehar should have greater priority than diversion through Pong.

Using some priority ranks for average, dry and wet years and keeping in mind the above priorities several sets of ranks for meeting the irrigation demands were used and tested. From the results, the values shown in Table 4.7 were adopted for subsequent studies.

In order to consider the effect of relative priorities between the storages and for different hydrologic states, sixteen sets of priority ranks (Table 4.8) were used along with the planned operation and these constitute the simulation study of the planned operation of the system. The value of X_1 and X_2 which define the hydrologic state of the system were varied between 0.7 ~~and~~ to 1.0 for X_1 and 1.0 to 1.2 for X_2 respectively. The results of simulation include the details of monthly, annual and total period summaries of the process.

TABLE 4.6 RULE CURVES+

1. Bhakra Reservoir

Maximum Capacity=7.644 m.a.

Hydrologic State	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	April	May
Average	0.2873	0.5937	0.9381	1.0000	0.9260	0.8032	0.7213	0.5877	0.4829	0.3812	0.3045	0.2
Dry	0.2224	0.4213	0.6267	0.6720	0.6478	0.6091	0.5477	0.4626	0.3768	0.3003	0.2415	0.2
Wet	0.2873	0.6297	0.9750	1.0000	0.9327	0.8166	0.7414	0.6145	0.5164	0.4214	0.3514	0.3

2. Pong Reservoir

Max. Capacity = 6.952 m.a.f.

Hydrologic State	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	Ma
Average	0.1367	0.3491	0.7568	0.8125	0.6714	0.5480	0.4662	0.4611	0.4105	0.2862	0.3083	0.2
Dry	0.1504	0.2475	0.2887	0.2645	0.2169	0.1722	0.1682	0.1608	0.1588	0.1516	0.1552	0.1
Wet	0.1367	0.3769	0.7600	0.8125	0.6781	0.5614	0.4863	0.4879	0.4440	0.3264	0.3477	0.2

+ Desired end of month storage level as a ratio of full capacity.

TABLE 4.7 PRIORITY RANKS FOR IRRIGATION AND POWER DEMANDS

Hydrologic State	Name of Node							
	Bhakra	Pong	Pandoh	Dehar	Nangal	Rupar	Harike	Mukerian
Average	14	20	20	8	10	12	16	20
Dry	14	20	20	8	10	12	16	20
Wet	14	20	20	8	10	12	16	20

TABLE 4.8 PRIORITY RANKS FOR RULE CURVES

Reservoir	Hydrologic State	Simulation Runs															
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Bhakra	Average	10	6	20	14	20	25	30	20	6	15	10	14	8	16	12	50
	Dry	8	4	18	12	15	25	25	18	4	10	8	12	6	12	8	30
	Wet	12	8	22	16	20	25	30	22	8	15	12	16	8	16	12	50
Pong	Average	14	25	18	14	50	60	50	25	14	22	25	25	120	35	10	20
	Dry	12	25	18	12	25	40	50	25	12	15	25	20	100	25	6	15
	Wet	16	25	18	16	50	60	50	25	16	22	25	25	120	35	10	20

4.4.3 Results and conclusions

i) Various values of X_1 and X_2 to define the hydrologic states of the system were tried and finally it was concluded that values of $X_1 = 0.90$ and $X_2 = 1.10$ was seen reasonable for the Beas-Sutlej system;

ii) Initially Bhakra reservoir alone was taken as spill reservoir. For some of the cases considered, Pong reservoir became full after about sixth year and because of the limit of the capacity of Beas-Sutlej link and no spill permitted at Pong there is no feasible solution and this indicated that Pong should also be considered as a spill reservoir;

iii) The assumed demand for the simulation are much larger than the inflows and in large number of years, there is scarcity particularly from March to June and these occured at Rupar and Harike which had the lowest priority. This indicated that in order to keep to deficit within limits, it is necessary to reduce the demands in some of the years. The inflows in 8th, 10th and 12th years are less by around five million acre ft each than the average year demands, and so the demand in these years are to be reduced to atleast dependable year demands;

iv) Variation of the priority ranking between storages for different hydrologic states indicated that :

a) Priority of storage at Pong should be less than that of Bhakra;

b) Priority for storage at Bhakra should be lower than that for demands and can at best be equal to that for the lowest priority demand;

c) Priority for storage in average and wet years should be the same. The priority for storages in a dry year may be slightly higher in order to avoid the large deficit at the end of water year or in the beginning of next water year; and

v) It is necessary to modify the rule curves for a better operation.

4.5 Improvements in Reservoir Operation

The simulation study of planned operation of Beas - Sutlej system indicate that the operation of the system can be improved significantly by modifying the rule curves and improving the value judgement for demands and storage under improved operating rule curve.

4.5.1 Modification of the rule curve

The planned operation of B.D.O. adopted in the study is indicated in Table 4.6. It shows that planned storage at the end of May and June as well as other months are different for the three states. The storage at the end of May is influenced by the inflows in the previous year and it should reflect the desirability of carryover in wet years and deplotion in dry years, but in June, the state depends very much on the carry-over of the previous year and the inflow and

demand in a year may differ very much from the end of the year storage. It is hence not possible to adopt different initially desirable storages at the end of June.

Using the general criteria that planned end of June storage should be the same in each reservoir for all states; the end of the year storage should reflect the possibilities of carry over and depletion; the reservoir fills up rapidly in the months of June to September and depletes from October to May or June, several modifications for the desired monthly storage levels for the different states in the two reservoirs were tried and the following rule curves are considered to be an improvement over the planned operation of B.D.O. (Table 4.9). It may be seen that the reservoir fills up quicker in an average year than in dry year and in turn it fills up quicker in a wet year than in an average year. The end of year storage in a dry year is less than that in an average year which in turn is less than that in a wet year. The general trend of the rule curve is similar to that of the planned operation except for some further modification in the end of month storages for August and April.

4.5.2 Ranking of priorities

Simulation of the planned studies as well as the improved operation indicate diversion through Pong from Harike while storage and capacity were available through Dehar and Bhakra. In order to eliminate this problem, the priority for

TABLE 4.9 MODIFIED RULE CURVES[+]

1. Bhakra Reservoir — Max. Capacity = 7.644 m.a.f.

Hydrologic State	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	March	April	May
Average	.3438	.5642	.9086	.9795	.8965	.7737	.6918	.5582	.4534	.3517	.2950	.2578
Dry	.3438	.4567	.6621	.7074	.6832	.6445	.5831	.4980	.4122	.3357	.2769	.2578
Wet	.3438	.5997	.9750	.9900	.9032	.7871	.7119	.5850	.4869	.3919	.3419	.2908

2. Pong Reservoir — Max. Capacity = 6.952 m.a.f.

Hydrologic State	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	April	May
Average	.1367	.3491	.7568	.8125	.6714	.5480	.4662	.4611	.4105	.2862	.2483	.223
Dry	.1367	.2338	.2750	.2508	.2032	.1585	.1545	.1471	.1451	.1379	.1370	.136
Wet	.1367	.3769	.7600	.8125	.6781	.5614	.4863	.4879	.4440	.3264	.2877	.277

[+] Desired end of month storage level as a ratio of full capacity.

demand at Harike was reduced by changing the rank from 16 to 25.

In order to study the priority in meeting the demand at Bhakra exclusively in the interest of power, four simulation runs were done with changing demands as indicated in Table 4.10 and with priorities as indicated in Table 4.11.

4.5.3 Evaluation of system performance

The planned operation as per B.D.O. meets the specified irrigation and power demands. The planned energy generation in the components as well as the total system are taken from Tables 4.1 to 4.3 and are shown in Table 4.12.

Energy generated as well as the irrigation deficits vary over the months and over the years. For the purpose of the study the following details of the performance of the system are considered important (Tables 4.13 to 4.16).

i) Total annual and monthly irrigation deficits;

ii) Power generation at (Bhakra and Dehar), Pong, and the total power generation of the system in Kharif season and non-kharif season and water year respectively;

iii) The surplus or deficit of power in each of the sub-systems in Kharif season, non-kharif season and water year respectively, in comparison to planned values;

iv) An earlier study (Rao, 1976) of the system indicated that :

TABLE 4.10 POWER DEMAND AT BHAKRA

Years	Simulation Runs			
	I	II	III	IV
1,2,3,4,6,7,9,11,13	Average	Average	Nil	Nil
5	Dry	Dry	Nil	Dry
8, 10, 12	Dependable	Dependable	Nil	Nil

(Values as specified by B.D.O.)

TABLE 4.11 MODIFIED PRIORITY RANKS

Item	Hydrologic State	Simulation Run			
		I	II	III	IV
Demand at Bhakra	Average	35	26	35	60
	Dry	35	26	35	60
	Wet	35	26	35	60
Bhakra Storage	Average	30	30	30	30
	Dry	30	25	30	30
	Wet	30	30	30	30
Pong Storage	Average	50	50	50	50
	Dry	50	25	50	50
	Wet	50	50	50	50

1) Conjunctive use of surface and ground water resources is necessary;

2) Since excess energy is available in Kharif season, this may be used for pumping ground water to meet part of the irrigation demand and to this extent, the surface water releases may be reduced. The earlier study indicated that in Bhakra reservoir in Kharif season about 1500 acre ft. per month of water is required to generate 1 MW of power and this will pump 6000 acre ft. of ground water. Hence 1 MW of excess energy indicates a potential for saving 4500 acre ft of water from Bhakra releases and thus augmenting storage;

3) The amount of water saved indicated in column 25 of Tables 4.13 to 4.16 increases the head and energy generated in the subsequent period and this is not taken into account in this study.

Yet this amount of water is available for irrigation and this may meet partly or completely the irrigation defioits in the water year. Net water deficit,if any,in the water year is indicated in column 26 of Tables 4.13 to 4.16.

4) This deficit may be met by diverting energy from outside the system and the amount of energy in MW months required for meeting these deficits are indicated in column 27 of Tables 4.13 to 4.16.

TABLE 4.12 PLANNED ENERGY++ GENERATION

Hydrologic State	Total inflow in Acre Ft.	In Kharif Season			In Non Kharif Season			In the Water Year		
		Bhakra + Dehar	Pong	Total+	Bhakra + Dehar	Pong	Total+	Bhakra + Dehar	Pong	Total+
Average	28288760	6102	1221	8093	6168	1159	8405	12270	2380	16498
Dry	17844884	4972	573	6315	4421	178	5677	9393	751	11992
Dependable ~~Wet~~	22971018	5513	877	7160	5155	658	6891	10668	1535	14051

\+ Includes energy generated at Nangal

++ Energy is in M.W.months

4.5.4 Discussion of results

A comparison of the generated energy in simulation runs with planned demand indicates that surplus energy is generated even in a dry year during the Kharif period and there is a deficit of energy during rabi season in average and dry years. Rao (1976) has suggested the use of surplus energy in Kharif to pump ground water by tube wells and hence reduce the surface water releases in Kharif for meeting irrigation demands. This will result in a higher storage during and at the end of filling period. It will also lead the availability of larger amount of water and energy in the depletion period.

Results of simulation run I indicate that irrigation and energy deficits are eliminated in a number of years and are otherwise reduced in other years. For example the irrigation deficits in years 2nd, 6th, ~~11th~~ and 13th are eliminated and the irrigation deficits in years 3, 7, 9 10 and 1~~0~~ are reduced. It is also seen that ~~20~~ 17 to ~~24~~ 18 MW months of energy will be required to eliminate the deficits in years 7 and 10 respectively. The energy requirements in years 3rd and 9th are of a much higher order, viz, 136 and 483 MW months. If energy of these magnitudes is available from outside the system, it is possible to eliminate irrigation deficits even in these years provided that adequate tube wells are also available.

Simulation Run II assumes a higher priority for maintaining storage in dry years in comparision to wet years. The results indicate that the operation is similar upto 6th year and then differs from 7th year onwards, while the variations are erratic from 8th to 11th year. The energy deficit is much larger in the 12th year in Kharif period and the energy surplus is smaller in the 13th year in simulation Run II in comparison to simulation Run I. Furthermore the amount of energy to be imported from outside for meeting the irrigation deficits are also larger in 7th, 9th, 10th and 12th years in simulation Run II. It is also seen that surpluses and deficits of energy are generally smaller in simulation Run II than those in simulation Run I.

Simulation Run III eliminates release from Bhakra on consideration of power. Simulation Run IV considers power demand at Bhakra only for the dry year 5th with the lowest priority. The results indicate that -

i) The fluctuation in energy is larger for Run III than Run IV;

ii) There is energy deficit in the 5th year in rabi season in Run III even though there is a surplus in an entire year;

iii) The energy generation in Run III is smaller than that of Run IV by 126 MW months;

iv) There is a large system loss in month 3rd of 6th year for Run III which is absent in Run IV; and

v) The irrigation deficit for 6th year is smaller for Run III than for Run IV and comparable in other years.

From the above results it is generally seen that energy releases from Bhakra need not be specified. Depending upon the relative value of irrigation deficit versus energy, at best those may be specified for dry years. In the absence of such value systems, it is inferred that Simulation Run IV is preferable.

4.6 Conclusions

The study indicates the following :

i) Rule curves and priorities as given in Tables 4.9 and 4.11;

ii) Irrigation demands and priorities as indicated in Tables 4.1 to 4.3 and 4.7; and

iii) Power demands and priorities as indicated for Simulation Run IV in Tables 4.10 and 4.11 lead to an improved operation of the system.

Further improvement of the system performance is possible by modification of the simulation programme in the following respects :

i) Incorporation of better algorithm for estimating the energy generation in the system;

ii) In some time periods diversion through Pong are indicated while capacity through Dehar and at Bhakra are available.

In these cases it is necessary to divert flow through Dehar even though the out of Kilter algorithm indicates diversion through Pong;

iii) Incorporation of subroutine to determine energy surpluses if any during kharif period, utilization of available tube wells for pumping ground water during this period to the extent necessary in conjunction with surface water releases, and modifications in SIMYLD II programme for correcting releases and storages appropriately; and

iv) Incorporation of flow and demand forecasting as well as suitable flexible control rules for the rule curves.

TABLE 4.13 RESULTS FOR SIMULATION RUN NO. I

YEAR	TOTAL INFLOW ACRE FT.	HYDROLOGIC STATE	IRRIGATION DEMAND ACRE FT.	IRRIGATION DEFICIT JULY TO JUNE: AMOUNT IN ACRE FT.	IRRIGATION DEFICIT JULY TO JUNE: DETAILS	POWER* GENERATED — POWER IN KHARIF: BHAKRA + DEHAR	POWER IN KHARIF: PONG	POWER IN KHARIF: TOTAL	POWER IN NON KHARIF: BHAKRA + DEHAR	POWER IN NON KHARIF: PONG	POWER IN NON KHARIF: TOTAL	TOTAL POWER: BHAKRA + DEHAR	TOTAL POWER: PONG	TOTAL POWER: TOTAL	SURPLUS (+) OR DEFICIT (-) — SURPLUS OR DEFICIT IN KHARIF: BHAKRA + DEHAR	IN KHARIF: PONG	IN KHARIF: TOTAL	SURPLUS OR DEFICIT IN NON KHARIF: BHAKRA + DEHAR	IN NON KHARIF: PONG	IN NON KHARIF: TOTAL	SURPLUS OR DEFICIT IN WHOLE YEAR: BHAKRA + DEHAR	IN WHOLE YEAR: PONG	IN WHOLE YEAR: TOTAL	ACRE FT WATER THAT CAN BE STORED BY SURPLUS ENERGY IN KHARIF	IRRIGATION DEFICIT AFTER USING SURPLUS ENERGY (ACRE FT.)	ADDITIONAL POWER* REQUIRED TO MEET DEFICIT
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
1	30778231	WET	27869452	NIL	NIL	6566	1202	8538	6206	1493	8777	12772	2695	17315	+464	-19	+445	+38	+334	+372	+502	+315	+817	2002500	NIL	NIL
2	25108895	AVRG.	27869452	922286	MAY	6536	1296	8602	6016	831	7925	12552	2127	16527	+434	+75	+509	-152	-328	-480	+282	-253	+29	2290500	NIL	NIL
3	26838606	AVRG.	27869452	1615422	49629 (MAR) 177398 (APR) 1039675 (MAY) 348720 (JUNE)	6263	1238	8271	6148	768	7994	12411	2006	16265	+161	+17	+178	-20	-391	-411	+141	-374	-233	801000	814422	136
4	29491541	WET	27869452	NIL	NIL	6377	1127	8274	6424	1312	8814	12801	2439	17088	+275	-94	+181	+256	+153	+409	+531	+59	+590	814500	NIL	NIL
5	17897518	DRY.	16757756	NIL	NIL	5330	767	6867	4534	307	5919	9864	1074	12786	+358	+194	+552	+113	+129	+242	+471	+323	+794	2484000	NIL	NIL
6	24735881	WET	27869452	2314295	448401 (APR) 1624150 (MAY) 241744 (JUNE)	7124	1025	8919	5274	844	7146	12348	1869	16065	+1022	-196	+826	-944	-315	-1259	+78	-511	-433	3717000	NIL	NIL
7	27359591	WET	27869452	511751	511751 (MAY)	6179	1234	8183	6464	867	8409	12643	2101	16592	+77	+13	+90	+296	-292	+4	+373	+279	+94	405000	106751	18
8	21858098	DEP.	21550876	NIL	NIL	5823	879	7472	5784	221	7083	11607	1100	14555	+310	+2	+312	+629	-437	+192	+939	-435	+504	1404000	NIL	NIL
9	24800488	WET	27869452	3709257	1421913 (MAR) 464307 (APR) 1316451 (MAY) 506586 (JUNE)	6349	1155	8274	5518	423	7019	11867	1578	15293	+247	-66	+181	-650	-736	-1386	-403	-802	-1205	814500	2894757	483
10	21761026	DEP.	21550876	567754	MAY	5532	961	7263	5055	705	6838	[illegible]	1666	14101	+19	+84	+103	[illegible]	[illegible]	[illegible]	-81	+131	+50	463500	104254	17
11	27003028	WET	27869452	1217976	4504 (APR) 1100179 (MAY) 113293 (JUNE)	6080	1420	8270	5931	866	7875	12011	2286	16145	-22	+199	+177	-237	-293	-530	-259	-94	-353	796500	421476	70
12	23406570	DEP.	21550876	NIL	NIL	5520	830	7120	5842	333	7253	11362	1163	14373	+7	-47	-40	+687	-325	+362	+694	-372	+322	NIL	NIL	NIL
13	25755685	WET	27869452	1504738	MAY	6771	1025	8566	5522	909	7509	12293	1934	16075	+669	-196	+473	-646	-250	-896	+23	+446	-423	2128500	NIL	NIL

* POWER IS IN M.W. MONTHS.

TABLE 4.14 RESULTS FOR SIMULATION RUN NO. II

YEAR	TOTAL INFLOW ACRE FT	HYDROLOGIC STATE	IRRIGATION DEMAND ACRE FT	IRRIGATION DEFICIT JULY TO JUNE: AMOUNT IN ACRE FT	IRRIGATION DEFICIT JULY TO JUNE: DETAILS	POWER* GENERATED: POWER IN KHARIF: BHAKRA + DEHAR	POWER IN KHARIF: PONG	POWER IN KHARIF: TOTAL	POWER IN NON KHARIF: BHAKRA + DEHAR	POWER IN NON KHARIF: PONG	POWER IN NON KHARIF: TOTAL	TOTAL POWER: BHAKRA + DEHAR	TOTAL POWER: PONG	TOTAL POWER: TOTAL	SURPLUS (+) OR DEFICIT (-): SURPLUS OR DEFICIT IN KHARIF: BHAKRA + DEHAR	IN KHARIF: PONG	IN KHARIF: TOTAL	SURPLUS OR DEFICIT IN NON KHARIF: BHAKRA + DEHAR	IN NON KHARIF: PONG	IN NON KHARIF: TOTAL	SURPLUS OR DEFICIT IN WHOLE YEAR: BHAKRA + DEHAR	IN WHOLE YEAR: PONG	IN WHOLE YEAR: TOTAL	ACRE FT WATER THAT CAN BE STORED BY SURPLUS ENERGY IN KHARIF	IRRIGATION DEFICIT AFTER USING SURPLUS ENERGY ACRE FT	ADDITIONAL POWER* REQUIRED TO MEET DEFICIT
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
1	30778231	WET.	27869452	NIL	NIL	6566	1202	8538	6206	1493	8777	12772	2695	17315	+464	-19	+445	+38	+334	+372	+502	+315	+817	2002500	NIL	NIL
2	25108895	AVRG.	27869452	1031438	MAY	6536	1296	8602	6006	831	7915	12542	2127	16517	+434	+75	+509	-162	-328	-490	+272	-253	+19	2290500	NIL	NIL
3	26838606	AVRG.	27869452	1615422	49629 (MAR) 177348 (APR) 1039675 (MAY) 348720 (JUN)	6263	1238	8271	6148	768	7994	12411	2006	16265	+161	+17	+178	-20	-391	-411	+141	-374	-233	801000	814422	136
4	24491541	WET	27869452	NIL	NIL	6377	1127	8274	6424	1512	6814	12801	2439	17088	+275	-94	+181	+256	+153	+409	+531	+59	+590	814500	NIL	NIL
5	17847518	DRY	16757756	NIL	NIL	5550	767	6867	4534	307	5919	9864	1074	12786	+358	+194	+552	+113	+129	+242	+471	+323	+794	2484000	NIL	NIL
6	24735381	WET	27869452	2314295	448401 (APR) 1624150 (MAY) 241744 (JUN)	7124	1025	8419	5224	844	7146	12348	1864	16065	+1022	-196	+826	-944	-315	-1259	+78	-511	-433	3717000	NIL	NIL
7	27559591	WET	27869452	665324	MAY	6119	1234	8183	6452	861	8397	12631	2101	16580	+77	+13	+90	+284	-292	-08	+361	-279	+82	405000	260329	44
8	21858098	DEF	21550876	657921	324704 (MAR) 71803 (APR) 261414 (MAY)	5825	879	7472	5713	224	7015	11536	1103	14487	+310	+2	+312	+558	-434	+124	+868	-432	+436	1404000	NIL	NIL
9	24800488	WET	27869452	3796513	1509170 (MAR) 464306 (APR) 1316451 (MAY) 506586 (JUN)	6301	1159	8230	5513	400	6991	11814	1559	15221	+199	-62	+137	-655	-759	-1414	-456	-821	-1277	616500	3180013	530
10	2116[illegible]	DEF.	21550876	616102	MAY	5532	961	7263	5055	696	6829	10587	1657	14092	+19	+84	+103	-100	+38	-62	-81	+122	+41	463500	152602	25
11	27003028	WET	27869452	1213473	1100180 (MAY) 113293 (JUN)	6080	1428	8278	5934	880	7892	12014	2308	16170	-22	+207	+185	-234	-279	-513	-256	-72	-328	832500	380973	63
12	23406570	DEF.	21550876	923464	280272 (OCT) 269666 (NOV) 373526 (DEC)	5520	774	7064	5782	399	7259	11302	1173	14323	+7	-103	-96	+627	-259	+368	+634	-362	+272	00	925469	154
13	[illegible]5755685	WET	27869452	1466896	MAY	6923	1011	8704	5577	945	7600	12500	1956	16304	+821	-210	+611	-591	214	-8[illegible]	+230	-424	-194	2741500	NIL	NIL

* POWER IS IN M.W. MONTHS.

TABLE 4.15 RESULTS FOR SIMULATION RUN NO III

YEAR	TOTAL FLOW	HYDROLOGIC STATE	IRRIGATION DEMAND ACRE FT.	IRRIGATION DEFICIT JULY TO JUNE: AMOUNT IN ACRE FT.	IRRIGATION DEFICIT JULY TO JUNE: DETAILS	POWER* GENERATED — POWER IN KHARIF: BHAKRA + DEHAR	PONG	TOTAL	POWER IN NON KHARIF: BHAKRA + DEHAR	PONG	TOTAL	TOTAL POWER: BHAKRA + DEHAR	PONG.	TOTAL	SURPLUS (+) OR DEFICIT (-) — SURPLUS OR DEFICIT IN KHARIF: BHAKRA + DEHAR	PONG	TOTAL	SURPLUS OR DEFICIT IN NON KHARIF: BHAKRA + DEHAR	PONG	TOTAL	SURPLUS OR DEFICIT IN WHOLE YEAR: BHAKRA + DEHAR	PONG	TOTAL	ACRE FT. WATER THAT CAN BE STORED BY SURPLUS ENERGY IN KHARIF	IRRIGATION DEFIC. AFTER USING SURPLUS ENERGY (ACRE FT.)	ADDITIONAL [illegible] REQUIRED [illegible]
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
1	30778231	Wet	27869452	NIL	NIL	6566	1202	8538	6156	1492	8726	12722	2694	17264	+464	−19	+445	−12	+333	+321	+452	+314	+766	2002500	NIL	NIL
2	25108895	AVRG.	27869452	773271	MAY	6631	1271	8672	6038	878	7994	12669	2149	16666	+529	+ 50	+579	−130	−281	−411	+399	−231	+168	2605500	NIL	NIL
3	26838606	AVRG.	27869452	1615424	49631 (MAR.) 1773981 (APR.) 1039675 (MAY) 348720 (JUNE)	6263	1238	8271	6148	768	7994	12411	2006	16265	+101	+ 17	+178	+20	−391	−411	+141	−374	−233	801000	814424	136
4	2449[illegible]541	Wet	27869452	NIL	NIL	6488	1127	8385	6382	1312	8772	12870	2439	17157	+386	−94	+292	+214	+153	+367	+600	+59	+659	1314000	NIL	NIL
5	17891518	Dry	16757756	NIL	NIL	5415	743	6928	4112	341	5531	9527	1084	12459	+443	+170	+613	−309	+163	−146	+134	+333	+467	2758500	NIL	NIL
6	24735301	Wet	27869452	1615632	1373886 (MAY) 241746 (JUNE)	6934	988	8692	5300	1053	7431	12234	2041	16123	+832	−233	+599	−868	−106	−974	−36	−339	−375	2695500	NIL	NIL
7	[illegible]	Wet	27869452	511751	MAY	6179	1234	8183	6464	867	8409	12643	2101	16542	+ 77	+13	+90	+296	−292	+ 4	+373	−279	+94	405000	106751	15
8	2185[illegible]	Dep.	21550876	NIL	NIL	5823	879	7472	5744	221	7043	11567	1100	14515	+310	+2	+312	+589	−437	+152	+899	−435	+464	1464000	NIL	NIL
9	24[illegible]488	Wet	27869452	3684727	1397383 (MAR) 464307 (APR.) 131645 (MAY) 506586 (JUNE)	6350	1159	8279	5520	429	7027	11870	1588	15306	+248	− 62	+186	−648	−730	−1378	−400	−792	−1192	837000	284[illegible]	475
10	[illegible]	Dep.	21550876	NIL	NIL	5532	961	7263	5011	697	6786	10543	1658	14049	+19	+84	+103	−144	+39	−105	−155	+123	−2	463500	NIL	[illegible]
11	[illegible]3020	Wet	27869452	779970	666673 (MAY) 113297 (JUNE)	6364	1338	8477	6019	989	8086	12388	2327	16563	+267	+117	+384	−149	−170	−319	+118	− 53	+65	1728000	NIL	NIL
12	[illegible]406570	Dep.	21550876	NIL	NIL	5570	830	7120	5775	333	7186	11295	1163	14306	+7	− 47	− 40	+620	−325	+295	+627	−372	+255	NIL	NIL	NIL
13	25155685	Wet	27869452	1504739	MAY	6809	1025	8604	5522	909	7509	12331	1934	16113	+707	−196	+511	−646	−250	−896	+61	−446	−385	2299500	NIL	NIL

TABLE 1.16 RESULTS FOR SIMULATION RUN NO. IV

YEAR	TOTAL INFLOW ACRE FT.	HYDROLOGIC STATE	IRRIGATION DEMAND ACRE FT.	IRRIGATION DEFICIT JULY TO JUNE: AMOUNT IN ACRE FT.	IRRIGATION DEFICIT JULY TO JUNE: DETAILS	POWER* GENERATED: POWER IN KHARIF: BHAKRA + DEHAR	POWER IN KHARIF: PONG	POWER IN KHARIF: TOTAL	POWER IN NON KHARIF: BHAKRA + DEHAR	POWER IN NON KHARIF: PONG	POWER IN NON KHARIF: TOTAL	TOTAL POWER: BHAKRA + DEHAR	TOTAL POWER: PONG	TOTAL POWER: TOTAL	SURPLUS (+) OR DEFICIT (-): SURPLUS OR DEFICIT IN KHARIF: BHAKRA + DEHAR	IN KHARIF: PONG	IN KHARIF: TOTAL	SURPLUS OR DEFICIT IN NON KHARIF: BHAKRA + DEHAR	IN NON KHARIF: PONG	IN NON KHARIF: TOTAL	SURPLUS OR DEFICIT IN WHOLE YEAR: BHAKRA + DEHAR	IN WHOLE YEAR: PONG	IN WHOLE YEAR: TOTAL	ACRE FT WATER THAT CAN BE STORED BY SURPLUS ENERGY IN KHARIF	IRRIGATION DEFICIT AFTER USING SURPLUS ENERGY (ACRE FT.)	ADDITIONAL POWER* REQUIRED TO MEET DEFICIT
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
1	30778231	WET	27869452	NIL	NIL	6566	1202	8538	6156	1493	8727	12722	2695	17265	+464	-19	+445	-12	+334	+322	+452	+315	+767	2002500	NIL	NIL
2	25108895	AVRG.	27869452	773271	MAY	6632	1271	8673	6038	878	7994	12670	2149	16667	+530	+ 50	+580	-130	-281	-411	+400	-231	+169	2610000	NIL	NIL
3	26838606	AVRG.	27869452	1615424	49631 (MAR) 1773980 (APR) 1039675 (MAY) 348720 (JUNE)	6263	1238	8271	6148	768	7994	12411	2006	16265	+161	+17	+178	-20	-391	-411	+141	-374	-233	801000	814422	136
4	29491541	WET	27869452	NIL	NIL	6377	1127	8274	6382	1312	8772	12759	2439	17046	+275	-94	+181	+214	+153	+367	+489	+59	+548	814500	NIL	NIL
5	17697518	DRY	16757756	NIL	NIL	5415	743	6928	4501	341	5920	9916	1084	12848	+443	+170	+613	+80	+163	+243	+523	+333	+856	2758500	NIL	NIL
6	24735381	WET	27869452	2169624	303729 (APR.) 1624151 (MAY) 241744 (JUN)	7098	1013	8881	5233	889	7200	12331	1902	16081	+996	-208	+788	-935	-270	-1205	+61	-478	-417	3546000	NIL	NIL
7	27359591	WET	27869452	511751	MAY	6179	1234	8183	6464	847	8409	12643	2101	16592	+77	+ 13	+ 90	+296	-292	+ 4	+373	-279	+94	405000	106751	18
8	21858098	DEP.	21550876	NIL	NIL	5823	879	7472	5744	221	7043	11567	1100	14515	+310	+2	+312	+589	-437	+152	+899	-437	+464	1464000	NIL	NIL
9	24800488	WET	27869452	3684723	1397383 (MAR) 464307 (APR) 1316447 (MAY) 506586 (JUNE)	6350	1159	8279	5520	430	7028	11870	1589	15307	+248	- 62	+186	-648	-729	-1377	- 400	-791	-1191	837000	2847723	475
10	21781026	DEP.	21550876	NIL	NIL	5532	961	7263	5011	696	6785	10543	1657	14046	+ 19	+ 84	+103	-144	+ 38	-106	-125	+120	-3	463500	NIL	NIL
11	27003028	WET	27869452	779920	666673 (MAY) 113247 (JUNE)	6368	1338	8476	6019	989	8086	12387	2327	16562	+266	+117	+383	-149	-170	-319	+177	- 53	+ 64	1723500	NIL	NIL
12	23406570	DEP.	21550876	NIL	NIL	5520	830	7120	5775	333	7186	11295	1163	14306	+7	- 47	- 40	+620	-325	+295	+627	-374	+253	NIL	NIL	NIL
13	25755685	WET	27869452	1504739	MAY	6809	1025	8604	5522	909	7509	12331	1934	16113	+707	-196	+511	-646	-250	-896	+61	-446	-385	2299500	NIL	NIL

* POWER IS IN M.W. MONTHS.

5. SUMMARY AND CONCLUSIONS

5.1. Summary

Water resources systems are generally large and complex. They consist of multiple units and serve multiple purposes. The multiple purposes are not wholly complementary. Several general or problem specific simulation models and computer programmes have been developed for analysing water resources systems SIMYLD II is a computer programme developed by Texas Water Development Board for simulating the hydrologic operation of a system of interconnected reservoirs within a basin or a multibasin water resources system. The study consists in implementing the SIMYLD II programme, validating it with available data and adapting it for the operation of Bhakra Beas system.

The original SIMYLD II programme was implemented in IBM 7044-1401 system at I.I.T. Kanpur and was adapted to meet the requirements of Bhakra Beas system.

Using 13 years of historical data, the Bhakra Beas system was simulated using the modified SIMYLD II model. The criteria for defining wet, average and dry years, the rule curves for operation in wet, average and dry years and the relative weightages for meeting different demands and for maintaining the rule curves are derived from simulation analysis. Results indicate that by using these

criteria the benefit from the operation of the system can be greatly increased. Further improvement of the model is also possible.

5.2. Conclusions

The following conclusions emerge from the study :

i) The original SIMYLD II programme can be implemented in IBM 7044-1401 system with minor modifications due to computer system and by limiting the dimensions of the problem to consider 13 nodes, 20 links and 13 years of monthly data.

ii) The programme needed additions and alterations a) because of difference in the water year b) because of gravity canal rather than pumped canal c) because of differing climate and the corresponding need for defining the state of the system to suit the climate and d) incorporation of energy developed from the system.

iii) Simulation of Bhakra Beas system indicates that it is possible to derive improved rule curves for the operation of the system in wet, average and dry years and the corresponding priorities between demands and maintaining the rule curves.

iv) Differing rule curves for wet, average and dry years incorporate the utility of carry over from wet years to dry years.

v) When a large number of computer programmes are available for simulation of water resources systems, it may be easier to adapt an existing programme than to write a new programme.

vi) Further modifications for optimization of the system and short term planning are possible.

5.3 Suggestions for Future Study

i) The present study is limited to the consideration of simulation of 13 years operation of Bhakra Beas system. Study of a longer period incorporating heuristic criteria to avoid diversion through Pong when diversion through Dehar is possible, and conjunctive integrated operation of the surface water-ground water system and with the additional details, will lead to better operation of the system.

ii) Simulation analysis using generated data for stream flow and irrigation and energy requirements, as part of a more comprehensive system planning study is also needed.

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